



Faculty of Engineering

**Experimental and Numerical Investigation to Visualizing Gas Standing
Waves of Air and Propane and the Effect on Smaller and Bigger
Diameter Tube with Acoustic Propagator**

Rashidah Binti Salim

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Experimental and Numerical Investigation to Visualizing Gas Standing
Waves of Air and Propane and the Effect on Smaller and Bigger Diameter
Tube with Acoustic Propagator

Rashidah Binti Salim

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any degree.

.....

Signature

Name: RASHIDAH BINTI SALIM

Matric No.: 15020351

Faculty of Engineering

Universiti Malaysia Sarawak

Date:

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ABSTRACT

The proposed study aims to demonstrate a standing wave with acoustic propagator. It demonstrates the link between sound pressure and sound waves. A review of literature on sound waves works with Ruben's Tube and benefit gain from learning sound analysis showed that this topic is continuously gaining its momentum. Nevertheless, application of acoustic from the study science and vibration can bring a lot benefit to the technology for human being such as application of horn antenna. Apart from that, a study on the different type of gas show how each type of gases reacts with the standing waves produced by speaker. Besides, using different size of tube diameter for acoustic propagator shows the effect to the standing wave output pattern. The most interesting in this experiment is to make Ruben's Tube into integrated system, where the tube would connect to laptop and used software Audacity for data analysis and data collection. All the program is created using the software where the change of frequency, amplitude and speed of gases automatically. Therefore, it would no longer used amplifier to find the suitable frequency to show the best standing wave pattern. Furthermore, the difference result analysis for air and propane gas show that air has higher speed of sound in both size tube diameter than propane. Also, the larger tube diameter makes the flame accelerates faster hence, when the flame touches the tube walls it would generate stronger pressure waves.

Keywords: Ruben's tube, standing wave, acoustic propagator.

**Penyiasatan Eksperimental dan Berangka Untuk Menggambarkan Gelombang Berdiri
Gas Udara dan Propana dan Kesan pada Tiub Garis Pusat Kecil dan Besar dengan
Penyebaran Akustik**

ABSTRAK

Kajian yang dicadangkan bertujuan untuk menunjukkan gelombang berdiri dengan penyebaran akustik. Ia menunjukkan hubungan antara tekanan bunyi dengan gelombang bunyi. Tinjauan kesusasteraan pada gelombang bunyi berfungsi dengan tiub Ruben's dan mendapat keuntungan dari analisis bunyi pembelajaran menunjukkan bahawa topik ini terus mendapat momentumnya. Walau bagaimanapun, aplikasi akustik dari sains kajian dan getaran boleh membawa banyak manfaat kepada teknologi untuk manusia seperti penggunaan antena tanduk. Selain itu, kajian mengenai jenis gas yang berbeza menunjukkan bagaimana setiap jenis gas bertindak balas dengan gelombang berdiri yang dihasilkan oleh pembesar suara. Di samping itu, menggunakan saiz garis pusat tiub yang berbeza untuk penyebaran akustik menunjukkan kesan kepada corak output gelombang berdiri. Yang paling menarik dalam eksperimen ini ialah membuat Ruben's Tiub menjadi sistem bersepadu, di mana tiub akan menyambung ke komputer riba dan menggunakan perisian Audacity untuk analisis data dan pengumpulan data. Semua program dibuat menggunakan perisian di mana perubahan kekerapan, amplitud dan kelajuan gas secara automatik. Oleh itu, ia tidak lagi digunakan penguat untuk mencari frekuensi yang sesuai untuk menunjukkan pola gelombang berdiri terbaik. Selain itu, analisis hasil perbezaan untuk udara dan gas propana menunjukkan bahawa udara mempunyai kelajuan bunyi yang lebih baik dalam garis pusat tiub berbanding dari gas propana. Garis pusat yang lebih besar juga membuat api bergerak lebih cepat dengan itu, apabila api menyentuh dinding tiub itu akan menghasilkan gelombang tekanan yang lebih kuat.

Kata kunci: *Tiub Ruben, gelombang berdiri, penyebar akustik.*

TABLE OF CONTENTS

	Page
DECLARATION	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
<i>ABSTRAK</i>	iv
TABLE OF CONTENTS	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
LIST OF ABBREVIATIONS	xii
CHAPTER 1: INTRODUCTION	1
1.1 Introduction	1
1.1.1 Characteristic of Sound Waves	1
1.1.2 Background of Ruben's Tube	3
1.2 Problem Statement and Research Questions	4
1.3 Hypothesis	4
1.4 Research Objective	5
1.5 Scope of Research	5
1.6 Research Novelty	6
1.7 Outline of Chapters	6

CHAPTER 2: LITERATURE REVIEW	7
2.1 Introduction	7
2.2 Theory in Calculation	7
2.3 Nodes and Antinodes	9
2.4 Related Work	10
2.4.1 Ruben's Tube as Integrated System	10
2.4.2 Relationship Sound Waves and Sound Pressure	15
2.4.3 Comparison Size of Tube Diameter and Material of Ruben's Tube	16
2.5 Summary	19
 CHAPTER 3: METHODOLOGY	 20
3.1 Introduction	20
3.2 Overall Research Outline	20
3.3 Research Design	22
3.4 Sampling Design	22
3.5 Fabrication	23
3.6 Audacity Frequency Generator	24
3.7 Experiment Setup for Small and Large Diameter Tube	24
3.8 List of Apparatus	25
3.9 Procedure	29
3.10 Experiment User Input	33
3.11 Calculation of Data	34
3.12 Experiment Testing Using Frequency Generator	35

3.13 Experiment Testing Using Software	35
3.14 Variables in the Experiment	36
3.14.1 Gas Pressure	36
3.14.2 Room Temperature	37
3.14.3 Production of Nodes and Antinodes	37
3.15 Summary	38
 CHAPTER 4: RESULT AND DISCUSSION	 39
4.1 Introduction	39
4.2 Air Gas for Small Diameter Tube	40
4.3 Air Gas for Big Diameter Tube	45
4.4 Propane Gas for Small Diameter Tube	50
4.5 Propane Gas for Big Diameter Tube	57
4.6 Graph Analysis	66
4.7 Summary	77
 CHAPTER 5: CONCLUSION AND RECOMMENDATION	 78
5.1 Conclusion	78
5.2 Recommendation for Future Work	80
 REFERENCES	 81
APPENDICES	83

LIST OF TABLES

		Page
Table 3.1	List of Apparatus for Ruben's Tube	25
Table 3.2	User Inputs for Experiment	33
Table 4.1	Result Analysis for Air Gas (Small Diameter)	40
Table 4.2	Result Analysis for Air Gas (Big Diameter)	45
Table 4.3	Result Analysis for Propane Gas (Small Diameter)	51
Table 4.4	Standing Waves Produces at Certain Frequency for Propane Gas (Small Diameter Tube)	51
Table 4.5	Result Analysis for Propane Gas (Big Diameter)	58
Table 4.6	Standing Waves Produces at Certain Frequency for Propane Gas (Big Diameter Tube)	58

LIST OF FIGURES

	Page
Figure 1.1 Sound is Pressure Wave of Sine Curve	2
Figure 2.1 Nodes and Antinodes Produces During the Experiment	10
Figure 2.2 Layout Area Using GUI MATLAB	12
Figure 2.3 Main Window Using MATLAB	12
Figure 2.4 Big Diameter Tube	17
Figure 2.5 Small Diameter Tube	17
Figure 3.1 Flow Chart of Overall Research Outline	21
Figure 3.2 Drill Holes into the Ruben's Tube	23
Figure 3.3 Experiment Setup for Small Diameter Tube	24
Figure 3.4 Experiment Setup for Big Diameter Tube	25
Figure 3.5 Apparatus Setup for Small Diameter Tube	30
Figure 3.6 Apparatus Setup for Big Diameter Tube	30
Figure 3.7 Experiment Concept for the Experiment	31
Figure 3.8 Schematic Diagram of Nodes and Antinodes	32
Figure 3.9 Experiment Setup of Ruben's Tube in the Laboratory	35
Figure 3.10 Number of Nodes and Antinodes Produces are Same	37
Figure 4.1 The First Harmonic in Small Diameter Tube	41
Figure 4.2 The Third Harmonic in Small Diameter Tube	42
Figure 4.3 The Fifth Harmonic in Small Diameter Tube	42
Figure 4.4 The Seventh Harmonic in Small Diameter Tube	43
Figure 4.5 The Ninth Harmonic in Small Diameter Tube	44

Figure 4.6	The Eleventh Harmonic in Small Diameter Tube	44
Figure 4.7	The First Harmonic in Big Diameter Tube	46
Figure 4.8	The Third Harmonic in Big Diameter Tube	47
Figure 4.9	The Fifth Harmonic in Big Diameter Tube	47
Figure 4.10	The Seventh Harmonic in Big Diameter Tube	48
Figure 4.11	The Ninth Harmonic in Big Diameter Tube	49
Figure 4.12	The Eleventh Harmonic in Big Diameter Tube	50
Figure 4.13	The First Harmonic in Small Diameter Tube	53
Figure 4.14	The Third Harmonic in Small Diameter Tube	54
Figure 4.15	The Fifth Harmonic in Small Diameter Tube	55
Figure 4.16	The Seventh Harmonic in Small Diameter Tube	55
Figure 4.17	The Ninth Harmonic in Small Diameter Tube	56
Figure 4.18	The Eleventh Harmonic in Small Diameter Tube	57
Figure 4.19	The First Harmonic in Big Diameter Tube	61
Figure 4.20	The Third Harmonic in Big Diameter Tube	62
Figure 4.21	The Fifth Harmonic in Big Diameter Tube	63
Figure 4.22	The Seventh Harmonic in Big Diameter Tube	64
Figure 4.23	The Ninth Harmonic in Big Diameter Tube	65
Figure 4.24	The Eleventh Harmonic in Big Diameter Tube	66
Figure 4.25	Actual Frequency at Small and Big Diameter Tube for Air Gas	67
Figure 4.26	Actual Frequency at Small and Big Diameter Tube for Propane Gas	68
Figure 4.27	Comparison Between Estimated and Actual Frequency in Small Diameter Tube for Air Gas	69

Figure 4.28	Comparison Between Estimated and Actual Frequency in Big Diameter Tube for Air Gas	70
Figure 4.29	Comparison Between Estimated and Actual Frequency in Small Diameter Tube for Propane Gas	71
Figure 4.30	Comparison Between Estimated and Actual Frequency in Big Diameter Tube for Propane Gas	72
Figure 4.31	Comparison Between Actual Frequency in Small Diameter Tube for Air Gas and Small Diameter Tube for Propane Gas	73
Figure 4.32	Comparison Between Actual Frequency in Big Diameter Tube for Air Gas and Big Diameter Tube for Propane Gas	74
Figure 4.33	Comparison Speed of Sound in Different Medium for Small Diameter Tube	75
Figure 4.34	Comparison Speed of Sound in Different Medium for Big Diameter Tube	76

LIST OF ABBREVIATIONS

AN	Anti-Nodes
GUI	Graphical User Interface
N	Nodes

CHAPTER 1

INTRODUCTION

1.1 Introduction

Sound propagates through air in the form of pressure waves (Gardner et al., 2009). However, it is difficult to watch standing waves with naked eye. Therefore, it can be visualized using the Ruben's Tube.

By passing flammable gas through a long metal tube with a small hole drilled on top, it is possible to create a line of individual flames. The height of each flame is related to the gas flow rate through the hole beneath it, which can be altered by modifying the gas pressure inside the tube (Gee, 2009). If this is done by a suitable choice of sound waves, standing waves can be established inside the tube, resulting in flame pattern. These can then be examined to establish relationships between the sound waves and the gas in which they travel.

1.1.1 Characteristics of Sound Waves

Characteristic of the sound waves come from the back and forth vibration of the particles of the medium through which the sound wave is moving. If a sound wave is moving from left to right through air, then particles of air will be displaced both rightwards and leftwards as the energy of the sound wave passes through it (Budak, 2009). This is what makes sound wave a longitudinal wave.

Air particles makes longitudinal motion therefore two kinds of regions are created according to the compression of particles as compressed together or as spread apart. When there is high pressure on a region than it is called compression however when there is a medium of low air pressure than it is called rarefaction (Amrita, 2013). A sound wave is formed of high and low-pressure regions therefore it is referred as a pressure wave.

The fluctuations in pressure as detected by a detector occur at periodic and regular time intervals. In fact, a plot of pressure versus time would appear as a sine curve. The peak points of the sine curve correspond to the compressions; the low points correspond to rarefactions; and the “zero points” correspond to the pressure which the air would have if there were no disturbance moving through it (Amrita, 2013). Example of pressure wave of sine curve shown in Figure 1.1.

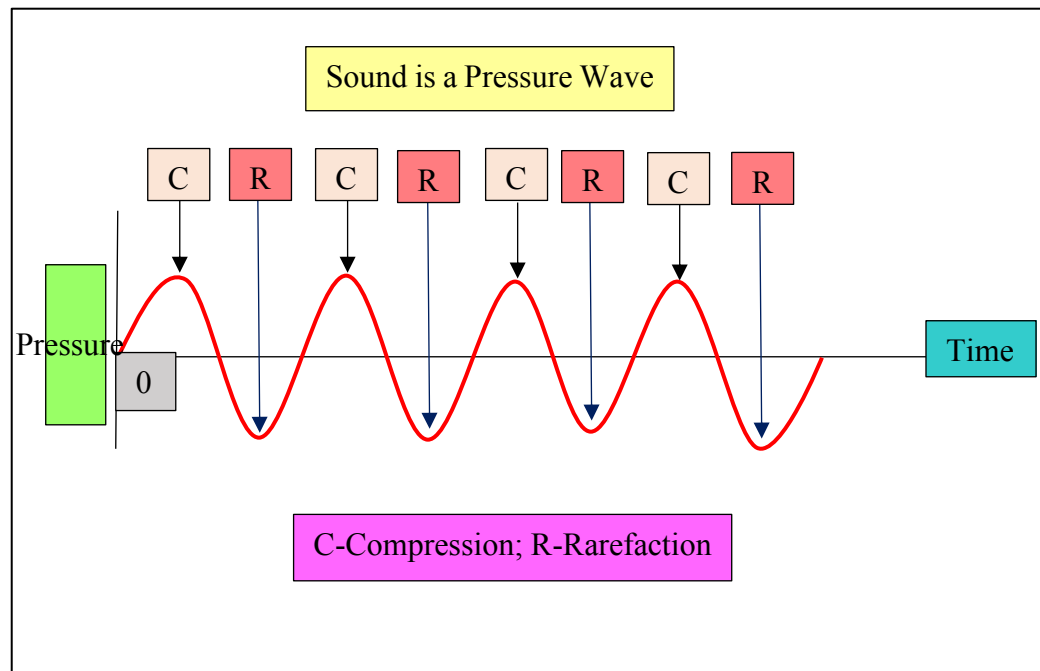


Figure 1.1: Sound is a Pressure Wave of Sine Curve

(Source: Salim et al., 2018)

Standing waves produced in Ruben's tube are open at one end and closed on the other. Therefore, the wave will start with a node and end with an antinode. According to Budak (2009), the reason for such behavior of the waves are the air pressure oscillation at the closed end since it has the greatest amplitude and forms an antinode.

1.1.2 Background of Ruben's Tube

Ruben's tube was invented by German physicists, Heinrich Rubens and Otto Krigar-Menzel. In 1905, Heinrich Rubens took a 4-metre-long tube and with 2-centimeter intervals and he drilled 200 small holes on the surface of the tube. Then he filled it with a flammable gas. When the gas was lighted, realized the rose of equal heighted flames escaping from the holes (Budak, 2009). This experiment revealed the acoustic standing wave behaviors.

After several trials, it concludes that when a sound is produced at the end of tube, it creates a standing wave which is equivalent to the wavelength of the sound given into the tube (Budak, 2009). The idea of Ruben's tube is coming from the demonstration of a standing wave by placing cork dust in a tube which was experimented in 1866 (Gee, 2009). In this experiment when a sound was made in the tube, the dust lined up as nodes and antinodes with the fluctuation of the sound wave in order to create a standing wave (Gee, 2009).

1.2 Problem Statement and Research Questions

Current system of Ruben's Tube is not rigid and it is not integrated which mean it needs to manually change the frequency, amplitude and speed of gas of the system during the experiment. Therefore, it is tedious and time consuming. Apart from that, different type of gas such as air and propane have different density and molar mass. Hence, it affects the pattern of flame and speed of sound inside the tube (Anderson et al., 2015). Besides, different size of tube diameter effects the flame pattern above the tube. Small and Big diameter tube has different effect on the flame propagation velocity inside the tube (Almarcha et al., 2015). Therefore, the primary research questions the researcher is trying to solve are:

- i. How to make Ruben's Tube into instrumentation system by using numerical software?
- ii. How does different type of gases effect the flow of gas vibration in Ruben's Tube?
- iii. How do different size of diameter tube effect the flame propagation velocity?

1.3 Hypothesis

The integrated system of Ruben's Tube is easier to change the frequency and speed of gas rather than using the frequency generator by manually. The pattern of standing waves output also change with difference types of gases and difference size of diameter tube.

1.4 Research Objectives

The objectives of this study are:

- i. To develop instrument system of Ruben's Tube through software Audacity for standing wave output with acoustic propagator.
- ii. To establish relationships between the speed of gas into different types of gases that is air and propane.
- iii. To investigate the effect on difference larger and smaller diameter tube with flame propagation velocity.

1.5 Scope of Research

This research explains the behavior of standing waves and sound pressure. A perfectly constructed Ruben's Tube would also show the property of the sound waves such as frequency, wavelength and speed. Besides, this research only used two types of gas that is air and propane due to limitation on money expenses. Apart from that, the researcher also wants to make Ruben's Tube into an integrated system where this experiment will use numerical software to change the speed of gases and frequency in it. Therefore, Ruben's Tube can be used as demonstrator in physic classes in many universities and engineering schools.

1.6 Research Novelty

There has been research on speed of gases using Ruben's Tube. However, that experiment only make comparison between air and propane by manually using frequency generator (Anderson et al., 2015). Therefore, this gives the idea to make comparison using numerical software which has higher accuracy than the manual set up.

1.7 Outline of Chapters

This section explains briefly what to expect in each chapter for this study.

Chapter 1- This chapter explains the history of Ruben's Tube and introduction of standing wave. It also explains the characteristic of sound waves inside the tube. This chapter also consist of problem statement and objective for this research study.

Chapter 2- This chapter provides a review on Ruben's Tube and some related work that has been done by others. Also, it consists theory in calculation that will be used in Chapter 4.

Chapter 3- This chapter explains the procedures and the methods using to complete this study. It provides the method of conducting this study and serve as a planning stage for data collection and result analysis.

Chapter 4- This chapter consists of result analysis for this research study. It will be in the form of table and graph. Also, it explains the finding of this study based on the objective of this experiment.

Chapter 5- This chapter concludes the research finding for this research study. It consists the recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section provides a review of literature which evolves within the context of the topic. This is based on the engineering and social science literatures. It also involves some related work about sound waves that has been done by others.

2.2 Theory in Calculation

This research used two type of gas that are air and propane to measure the effect of frequency on standing waves. This experiment compared the difference between the calculated and actual data for the experiment. The wavelength is calculated for different frequencies using the following equation.

$$f = \frac{v}{\lambda} \quad \text{Equation (1)}$$

The frequency and wavelength are inversely proportional. Where f is frequency, v is for speed of sound and λ is wavelength (Mahtani, 2012). For this experiment the velocity of sound in gas is calculated using:

$$v = \left(\frac{K}{\rho}\right)^{\frac{1}{2}} \quad \text{Equation (2)}$$

Where K is the modulus of bulk while ρ is density of the gas. Modulus of bulk is used to measure how compressible the substance to resistance.

$$K = \gamma \cdot p \quad \text{Equation (3)}$$

Where γ is specific ratio of the gas; air is 1.4 and propane is 1.127, p is pressure of gas in Ruben's tube. Then, solve for ρ using ideal gas law.

$$\rho v = nRT \quad \text{Equation (4)}$$

$$p = \frac{nRT}{v} \quad \text{Equation (5)}$$

$$\text{Substitute: } \rho = \frac{nM}{v} \text{ and } p = \frac{nRT}{v}$$

$$v = \left(\frac{K}{\rho}\right)^{\frac{1}{2}} \quad \text{Equation (6)}$$

$$v = \left(\gamma \cdot \frac{p}{\rho}\right)^{\frac{1}{2}} \quad \text{Equation (7)}$$

$$v = \left(\frac{\gamma \cdot nRT/v}{nM/v}\right)^{\frac{1}{2}} \quad \text{Equation (8)}$$

$$v = \left(\frac{\gamma \cdot R \cdot T}{M}\right)^{\frac{1}{2}} \quad \text{Equation (9)}$$

Where γ is specific ratio of gas, R is universal gas constant 8.314 J/mol.K, T is absolute temperature in Kelvin, and M is molecular mass. Finally, after the calculation, the velocity found for dry air at 20°C is 343.20 m/s and for propane at the same temperature is 249.51 m/s (Mahtani, 2012).

In this experiment, the frequency would increase. However, the number of nodes and antinodes would increase where more standing waves are produced. Wavelength can be calculated using:

$$\lambda = \frac{4L}{n} \quad \text{Equation (10)}$$

Where λ is wavelength, L is length of tube which is for this experiment will be 1.30 m.

2.3 Nodes and Antinodes

In this experiment, the tube is closed at one end. The number of nodes and antinodes produced are same (Bakar, 2007). It starts with nodes and ends it with antinodes. It stated that the maxima could occur at nodes or antinodes (Bakar, 2007).

Many years later, myriad of experiment has been done to prove the statement. It was claimed that the maxima of flame would be occur at antinodes (Gee, 2009). Under normal condition, at nodes the flame is yellow and tall, while at antinodes the flame is blue and short. Hence, it concludes that flame maxima occur at pressure nodes. However, under high sound intensities (140-150 dB) and variation of pressure occur inside the tube could make the maxima of flame reverse (Gee, 2009).

Besides, static gas pressure was important factor to decide the maxima of flame arise. Under normal static gas pressure, the flame maxima occur at pressure nodes and low static pressure maxima could happen at pressure antinodes (Salim et al., 2018). Therefore, the flame maxima could occur at pressure nodes and minima at pressure antinodes. However, the factor of sound intensity and static gas pressure can influence the location of flame maxima occur (Gee, 2009).

Bernoulli equation are used to make a simple model where can be used to check the mass flow rate inside the tube (Gardner et al., 2009). Under normal condition, the maxima occur at pressure nodes based on time-averaged mass flow rate. Nevertheless, increasing the sound level and decreasing the static pressure will reverse the effect in flame height which is flame maxima at the antinodes and flame minima at the pressure nodes (Gardner et al., 2009). Figure 2.1 shows the nodes and antinodes produce during the experiment.

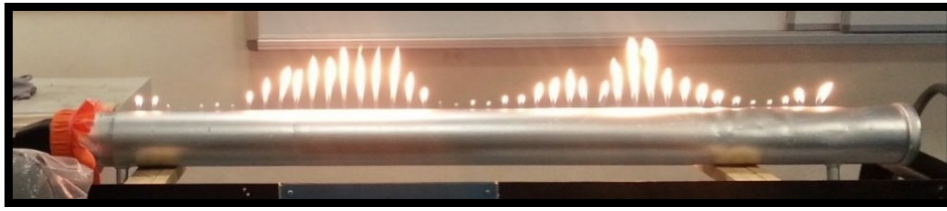


Figure 2.1: Nodes and Antinodes Produces During the Experiment

2.4 Related Work

Journals are reviewed to have better understanding about Ruben's tube. It focusing on using numerical software to make tube as integrated system, used difference type of gas to check speed of gas and frequency inside the tube and using difference diameter size of the tube to check the flame propagation which has strongly affect the occurrence of vortex flow inside the tube.

2.4.1 Ruben's Tube as Integrated System

Ruben's tube can be used altogether to make it as integrated system. For example, it can prove by investigation on the effect of frequency change on standing waves proves the sound wave is also pressure wave by vibration occur inside the tube (Budak, 2009). This experiment used same type of gas for entire experiment: propane gas. Distance between the tube and the speaker diaphragm does not change or not move to prevent the error during the experiment. After several data and calculation has been made, it shown that wavelength and the frequency generated are directly proportional. As the frequency increase, the number of antinodes and nodes increases and wavelength decrease shown the inverse relationship between wavelength and frequency.

During early experiment the author used music to watch the movement of the flame. Nevertheless, it is difficult to get precise result using music because it contains various frequency and it change continuously (Salim et al., 2018). Therefore, instead of using music, this experiment used software that specialized in record and edit sound such as Audacity®.

Besides, the characteristic of the tube which is the resonance frequencies are different than the calculated frequency explained in the experiment (Gardner et al., 2009). It suggests that the different between the resonance frequency during experiment is due to different size of diameter for the holes. The size of holes affects the behavior of the tube. Smaller and fewer holes decreases the resonance frequency shift. However, the hole cannot be too small or too far apart because it affects the performance during demonstration. In this experiment, MATLAB®-based on graphical user interface (GUI) was developed to complete circuit model (Abu Bakar, 2007). The example of GUI can be shown in Figure 2.2 and Figure 2.3 (Salim et al., 2018). This model consists various dimensions such as tube radius, hole spacing, number and size.

Also, the presence of speaker affects the result. This is due to speaker can change the resonance frequencies and effect the result during first few harmonics. Speaker itself has its own resonance and produce significant damping to the system.

Apart from that, digital processing is a higher theoretical course (Song et al., 2012). In the practical teaching process, teachers are generally more focus on the important basic concepts and theories to explain the derivation of the algorithm, which students would feel difficult to understand and accept. Doing the experiments helps students understand the curriculum, and put some abstract theory concrete. The students can analyze and looks problems with different points of view.

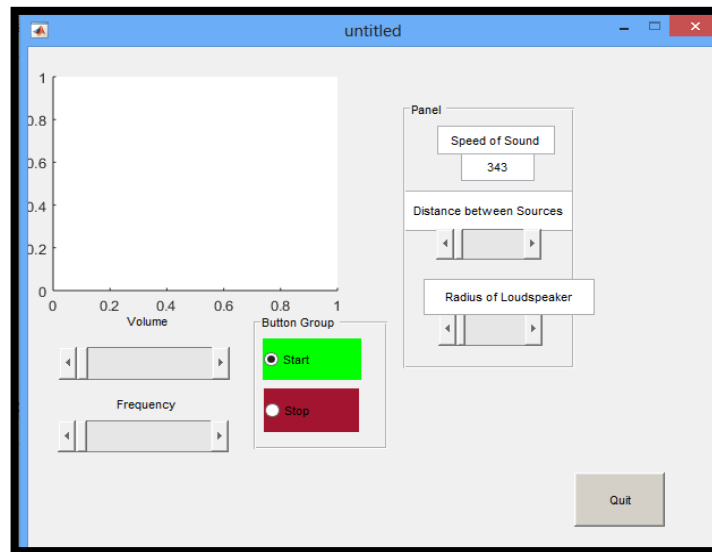


Figure 2.2: Layout Area Using GUI MATLAB
(Source: Salim et al., 2018)

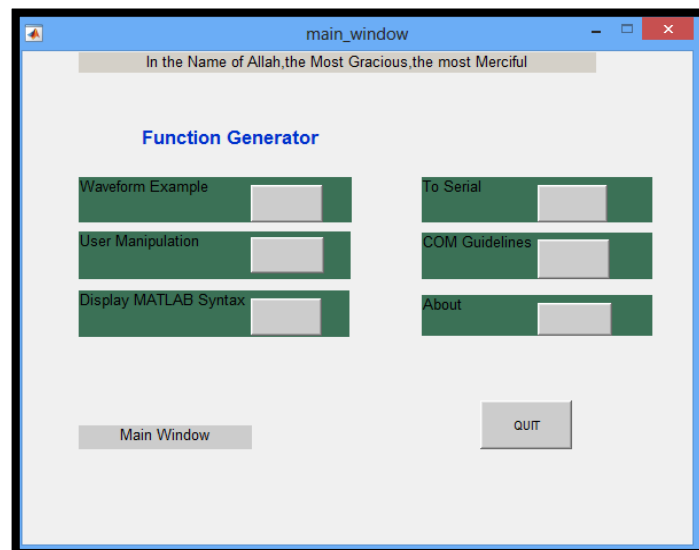


Figure 2.3: Main Window Using MATLAB
(Source: Salim et al., 2018)

Furthermore, tracking algorithms are used for stereoscopic video camera to track the motion and follow the signal of a dancer (Todoroff et al., 2010). Also, this research has built small and light wireless sensor system to be worn by the dancer. Firetrase stand for Fire, Tracking and Sensors. This research has collaboration with the pyro technician to develops real time software to control each of the ramp of 20 fire projectors height individually (Todoroff et al., 2010). Also, the researchers create a program of generator that have flexible pattern to make and combine different type of complex patterns used to control the movement of a dancer. However, there are difficulty to perform with the real fire. Hence, to overcome this problem, the researchers combine results from the project with the pitch detection algorithms for the Multimodal Guitar project. As a result, it could control many type sound transformations, pre-recorded sound sequences and specialization concurrently with the real flame.

In addition, there was direct demonstration of an audio-range line array that can be used to explain the interference of various sources in a laboratory or physic classroom. It developed software using graphical user interface by LABVIEW® that can permit real time control, sine wave of user specified frequency, amplitude, steering of the array and phase shading (Anderson et al., 2014). It consists for change in frequency, the angular shading by phase shading and reduces side lobes through amplitude shading. Apart from that, it used in total eight inexpensive loudspeaker array to test the software in an anechoic chamber and in a big classroom. The advantages of this software are it can switch on and off each individual loudspeaker, arbitrary phase and amplitude of the program. Also, numerical simulations were performed to study the effects of pressure waves on the development and stability of flames propagating in tubes (Xiao et al., 2010).

The numerical solution method is high in order in space and time, adaptive mesh refinement provides adequate resolution of flames, acoustic waves and boundary layers. It also has all the interaction with others. Series of distorted tulip flames (DTFs) and tulip flames (TFs) show the influence of tube length scale and aspect ratio for a range of tube sizes. Acoustic properties of the tube and pressure waves has important role in the flame evolution, especially in the formation and evolution of the series of increasingly wrinkled DTFs (Xiao et al., 2016).

The effect of external heat loss on the slow propagation of strongly-burning flames inside narrow heat recirculating tubes was investigated (Gauthier & Bergthorson, 2016). This study used a 2-D numerical model for reactive flow, including conjugate heat transfer, over a range of tube diameters spanning the micro-scale (small scale) and the meso-scale (larger scale). Flames in micro-scale has the extinction limit, however, flames in large diameter tubes such in meso-scale range, usually has blowout limit. 2-D model can show the flame shape efficiently than 1-D model. It also allows an increase in burning surface area which is has more stability to the system. Hence, choosing size tube diameter are important to the design of a stable burner optimized for heat transfer to an external heat load.

Besides, the researcher studied the upward propagation of a premixed flame in a vertical tube which has very lean mixture of gas (Higuera, 2011). By using single irreversible Arrhenius reaction model, this experiment doing numerical simulation with high activation energy. It is shown that the flow might become unstable when the fuel mass fraction is decreased and together with flame stretch due to strong curvature of the flame tip in narrow tube might be the reason for the minimum fuel mass fraction. Also, there was experiment and numerical investigation to describe methane ignition driven long wall coal mine explosions, which is one of the biggest industrial explosions (Fig et al., 2016).

The research is about doing investigation of methane combustion with flame propagation in horizontal cylindrical tubes and effect on different size of tube diameter. In the experiment part, the authors used horizontal tubes with one end allowed to vent to the atmosphere, and the other end to the solid wall. The tube diameter used are between 5 to 71 cm. Hence, it is proven that maximum laminar flame propagation velocity increases with tube diameter (Fig et al., 2016). Also, the 2-D simulations for these tubes were carried out with ANSYS Fluent.

2.4.2 Relationship Sound Waves and Sound Pressure

Ruben's tube helps to show the relationship between sound waves and sound pressure by doing demonstration with the fire which is one of the important objectives in this review paper (Anderson et al., 2015). It composed of a tube that is constructed to be airtight besides holes drilled at regular intervals across the length at the top of the tube. There exists a gas line and one end of the tube is fitted with a diaphragm. When the gas is pumped into the tube it will forced out from the holes. At this point the gas is ignited creating individual flames at each of the holes. When a frequency is played across the diaphragm, the resultant pressure in the tube causes the flames to vary in height. This experiment used two type of gas such as air and propane. To calculate the speed of gas, the authors make comparison between theory and the experiment. Ruben's tube to measure different wavelength with different frequencies (Mahtani, 2012). Calculation was made to predict the wavelength for different frequencies and compare it with the result obtain from the experiment. It was stated that high frequencies produced shorter wavelengths (Mahtani, 2012). This experiment used 300 Hertz (Hz) to 700 Hz to measure for different wavelength.

Three different trials were done to measure the averaged for each wavelength. Using percentage error analysis to compare the theoretical with the experiment values has achieve the objective of the experiment that is higher frequencies tend to have small wavelength.

The acoustic standing wave behavior are based on the height of flame produced above the tube (Gee, 2009). This research explains the history of Ruben's tube from the tube development and its operation. There are also commentary and other experiment involve the flame tube itself in the literature reviews. The explanation on flame maxima occur comes from various sources and opinion. Originally, it shows that the flame maxima could occur either at nodes and antinodes. During normal condition the flame maxima appear to be at nodes. However, during revised condition, the flame maxima could occur at antinodes due to the changes in sound intensity and static gas pressure that appear during the experiment (Budak, 2009).

2.4.3 Comparison Size of Tube Diameter and Material of Ruben's Tube

Difference in tube diameter also affects the performance of flame propagation of the tube. The experiment was conducted to investigate the premixed propane and methane-air flames propagating in tube 1.5-meter-long with diameters 54 mm and 94 mm (Almarcha et al., 2015). The tubes are open at one end and the other end is closed with an acoustic damper to remove thermos-acoustic instability inside the tube. This experiment distinguished by correlating the flame speed and the radius of curvature at the flame tip. The characteristic lengths are then related to the cut-off wavelengths estimated from linear theories and compared to previous results simulations. The example for different tube diameter is shown in Figure 2.4 and Figure 2.5.

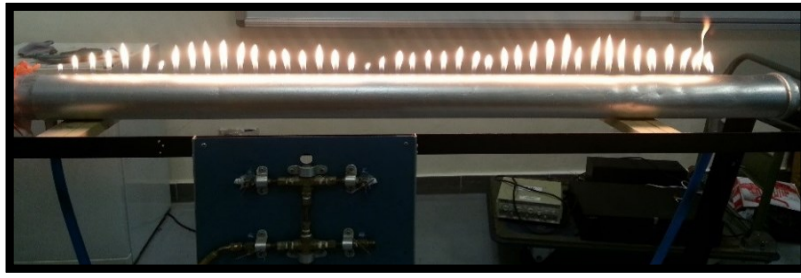


Figure 2.4: Big Diameter Tube



Figure 2.5: Small Diameter Tube

Besides, there is experiment used to investigate the function of small diameter tubes and swirl injectors for methane and propane/air mixtures (Shimokuri et al., 2011). By using 3.6 mm tube, it shows that a flame can propagate rapidly along the tube axis due to vortex bursting as shown in larger diameter tubes. Also, the propagation range increases the air flow rate, while the range decreases with decreasing in the air flow rate, and further decreasing can lead to a fail of propagation (Shimokuri et al., 2011). When the swirl intensity is increased, the flame propagation range in the equivalence ratio and in the air flow rate is widened. Flame propagation for methane gas shifted to fuel-lean side while for propane gas it shifted to fuel-rich side. These range are narrower than obtained in 31 mm tube which has larger diameter tube.

Apart from that, the experiment of flames in narrow circular tubes which is the tube diameter is not larger than the Zeldovich thickness and wall effects are important factor to considered (Jackson et al., 2007) The fuel-rich inflammable mixture is blown down the tube, that is open at one end and supports deflagration which is sometimes has steady and unsteady flow. The unsteadiness is characterized by periodic extinction and reigniting. There is also mathematical model that able to capture both the dynamics and the transitions in parameter space between steady solutions, unsteady solutions and a return to steady solutions.

Furthermore, it was claimed that when a flame passes through a tube that is open at both ends a self-induced fluctuating pressure or flow fields is created which the flame has to traverse (Yang et al., 2015). This experiment used fuel of propane-air flame and filmed it while travelling along a 20mm internal diameter quartz tube. During the experiment, the fluctuations in the flame's progression was observed to increase as the flame propagated, achieving a maximum oscillation amplitude of $\pm 10\text{mm}$ at 220 Hz that decayed as the flame progressed further towards the ends of the tube (Yang et al., 2015).

The changes of the periodic pressure gradients on the flame shape could be discerned the unburned reactants while pushed it through the products together with the corresponding rapid acceleration of the flame into the unburned mixture. The changes of the flame were observed by capturing the hydrocarbon (CH^*) and diatomic carbon (C_2) chemiluminescence using with a high speed colour camera. Hence, the CH^*/C_2 ratio was observed showed the lower ratio as the flame was pulled back towards the burned mixture and higher ratio when the flame was pushed forwards.

Also, some experiment are conducted to study the effect of both the bend angle and bend position of flame acceleration in pipes (Zhu et al., 2016). There are three stage for flame acceleration in a pipe bend. For example, the flame speed increased before the bend, increased again after decreasing for a short distance in the bend and decreased of flame speed during reversal of flame in the bend that led to additional turbulence which enhanced the flame acceleration after the bend. All three stage has similar case due to decreasing amplitude of the flame speed in the bend increase with a decrease in the bend angle. The flame speeds in the bend were ordered such that $52^\circ < 90^\circ < 145^\circ$ but the maximum flame speeds in the pipe were in the opposite order (Zhu et al., 2016). However, both the flame speeds in the whole pipes increased as the bend's position away from ignition point increased.

2.5 Summary

This chapter provides review for myriad of experiment that has relationship to standing wave, integrated system and effect of using difference type of tube diameter. A lot of journal has been published to explain the behavior of standing wave inside the tube. These reviews help to understand the behavior of standing wave through experiments all over the years. Therefore, further examining the Ruben's Tube will give the researcher the idea of investigating effect of sound waves on standing waves.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This section of the report explains the procedures and the methods used to complete this study which is the transformation of the problem and information collected from experiments of Ruben's tube to show the sound waves produced by music. A research methodology is defined as a systematic observation by using certain methods based on the subject.

3.2 Overall Research Outline

This section of the report explains the procedures and the methods used to complete this study which is the transformation of the problem and information collected from experiments of Ruben's Tube. Overall outline of this research study is displayed through the flow chart in Figure 3.1.

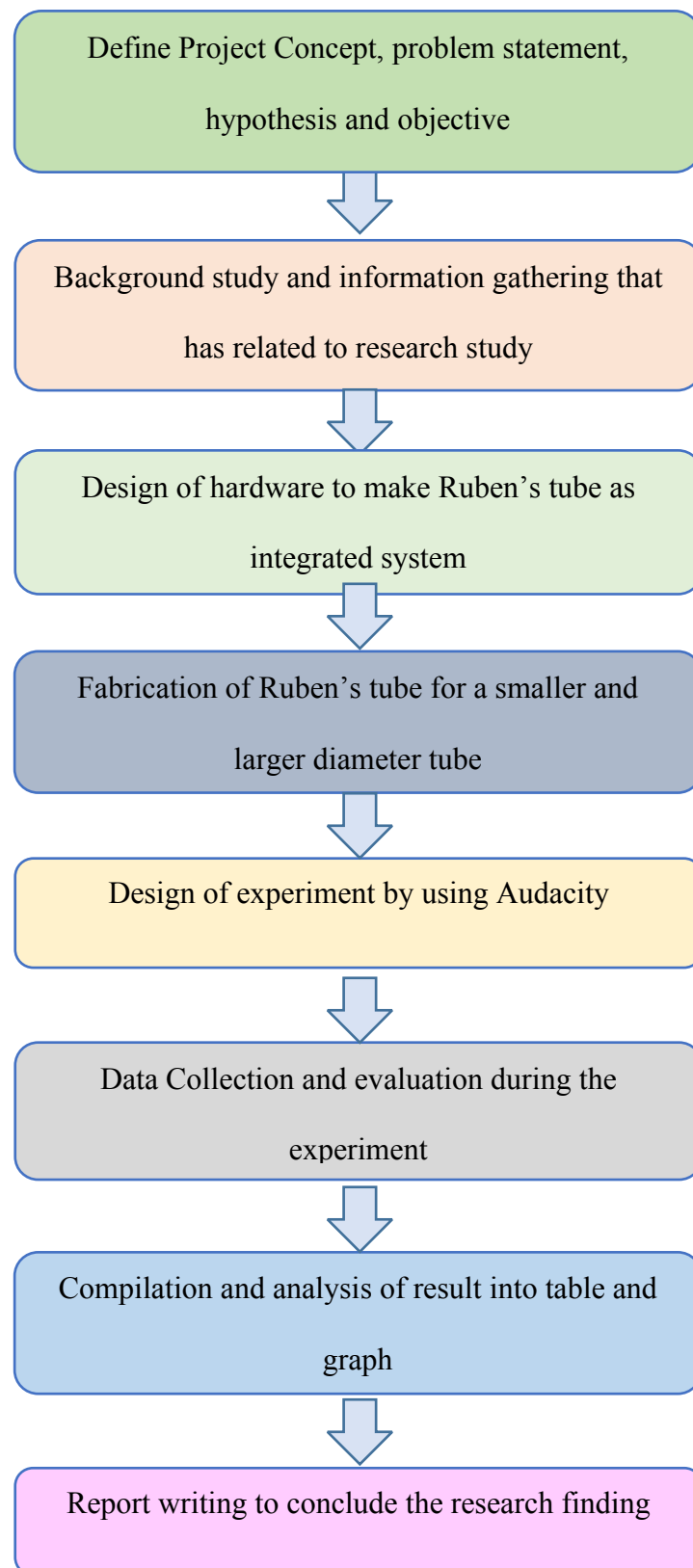


Figure 3.1: Flow Chart of Overall Research Outline

3.3 Research Design

Research design is the conceptual structure within which research would be conducted. First, the researcher needs to fabricate the Ruben's Tube. Then, uses the software that specialized is for inspecting and analyzing the content of audio files to show the waveform and spectral visualization tools with annotations possible. As an integrated system, Ruben's Tube would be no longer connected to the amplifier, but it would be directly connected to the laptop. By using numerical software, it would be efficient to collect data directly from the source. Apart from that, usually changes of frequency and speed of gas will be conducted manually, however now the researcher will be using the program by numerical software to change it.

3.4 Sampling Design

In this experiment, the researcher used two different types of gas such as air and propane to show speed of sound in various gases. Then, different diameter sizes of tube are used to show the relationship of flame propagation velocity. Besides that, the current Ruben's Tube is changed into an integrated system where the change of frequency, amplitude and speed of gases would be automatically done. This experiment used numerical software Audacity that can be used together with a Ruben's Tube and act as one whole system where the changes of parameter can be made through software.

3.5 Fabrication

Fabrication is the action or process of manufacturing or invention of single unit as a solo component or as unit of a bigger assemble components. For the purpose of this project, the researcher needs to fabricate the Ruben's Tube that shows the sound waves using flames produced from the tube as shown in Figure 3.2. Metal fabrication is used to building the metal structure by cutting, bending and assembling process.

A metal tube with small holes drilled down its length. One end is capped off with a solid cap and the other end is covered in a sound permeable membrane. This tube, when fed with propane it can demonstrate standing waves in sound via the produced flames.

Besides that, Ruben's tube will act like a tube with one end closed. It has a certain frequency that is played through one end of the tube, the sound waves bounce off the end cap on the other side and reflects back into the incident wave, both interfering constructive and deconstructive, creating the nodes and antinodes seen in the flame.



Figure 3.2: Drill Holes into the Ruben's Tube

3.6 Audacity Frequency Generator

This experiment used Audacity as a replacement of frequency generator. The frequency decided to be between 50 Hz to 500 Hz. It also shows the pattern of graph for each frequency. Amplitude and pressure of gas is kept constant.

3.7 Experiment Setup for Small and Large Diameter Tube

Ruben's Tube would be connected to laptop and using numerical software for data analysis and data collection. All the program is created using the software where the change of frequency, amplitude and speed of gases automatically. Hence, there would be no more using amplifier to find the right frequency of sound waves where the standing flame would be shown through Ruben's Tube. Actual experiment setup for small and big diameter tube can be shown in Figure 3.3 and Figure 3.4.

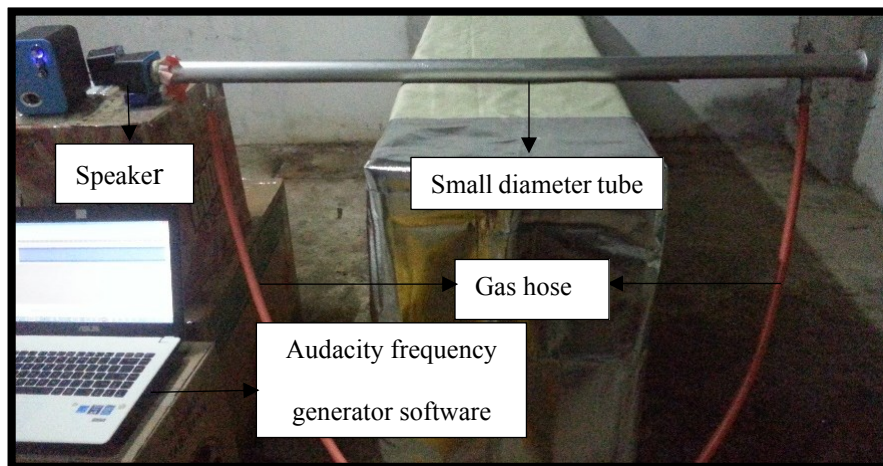


Figure 3.3: Experiment Setup for Small Diameter Tube

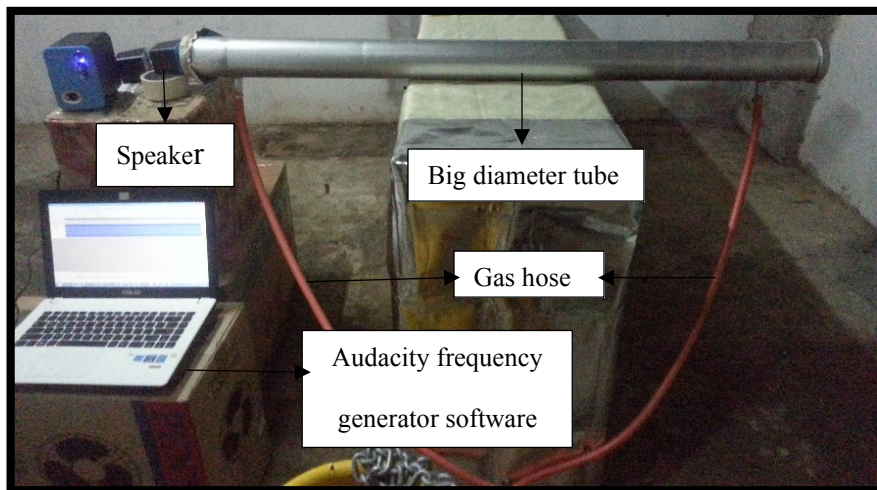


Figure 3.4: Experiment Setup for Big Diameter Tube

3.8 List of Apparatus

Table 3.1 shows the basic apparatus to made Ruben's tube.

Table 3.1: List of Apparatus for Ruben's Tube

List of Apparatus	Picture of the Apparatus
1. Pipe-Cast Iron -Act as acoustic propagator to show standing wave inside the tube. It has small and big diameter tube with same other tube dimensions.	

Table 3.1 continued

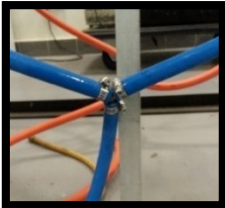
2. Gas Tank-Propane -Supply gas propane to the tube and to show the standing wave pattern above the tube in the form of flame.	
3. Frequency Generator -Supply frequency signal to the tube. It connects with the power supply and used to monitor the frequency inside the tube.	
4. Gas Hose -Used to join gas tank to the tube.	
5. Gas Regulator -Used to control the gas flow entering the tube. The gas flow keeps monitored to prevent overflow of gas during the experiment.	

Table 3.1 continued

6. Lighter Gas -To light the gas at the top of tube	
7. Speaker 1 -Act as a frequency generator and supply frequency signal to the tube. This is the first speaker used to testing with the set-up experiment. However, it cannot produce the sin wave successfully even though the frequency keeps getting higher.	
8. Speaker 2 -Act as a frequency generator and supply frequency signal to the tube. This is the second speaker used to test with the Audacity and proved to be more compatible with the rest of hardware.	

Table 3.1 continued

9. Pressure Controller -To control pressure inside the tube. The pressure is the constant variable for this experiment. It will keep constant for the whole experiment.	
10. Rubber sheet -To close the other end of tube to ensure the fire does not go out when lighten the tube. It also needs to change after few times conducting the experiment to prevent gas leaking from the tube.	
11. Hose Clips -Seal a hose to the fitting to ensure the gas does not flow out.	
12. T-connector -To connect the gas hose from all three ways.	

Table 3.1 continued

13. Brass Fittings -Join the gas hose to the tube.	
14. PVC Tape -Tape the speaker with box and to utilize the production of sin wave.	
15. White Tape -Tape the gas fitting to make it tight to the tube and to prevent gas leaking from the fitting.	

3.9 Procedure

Ruben's tube is made from cast iron. This material will be used to check the material vibration inside the Ruben's tube. Ruben's tube will begin with cast iron tube of length 1.30 m and a diameter of 4 cm. The construction of Ruben's tube starts by measuring out a distance of 10 cm from each end of the tube. Then, proceeded to drill 43 holes in a line each a distance of 1 inch apart from each other with the diameter of each hole being 2 mm round as shown in Figure 3.5.

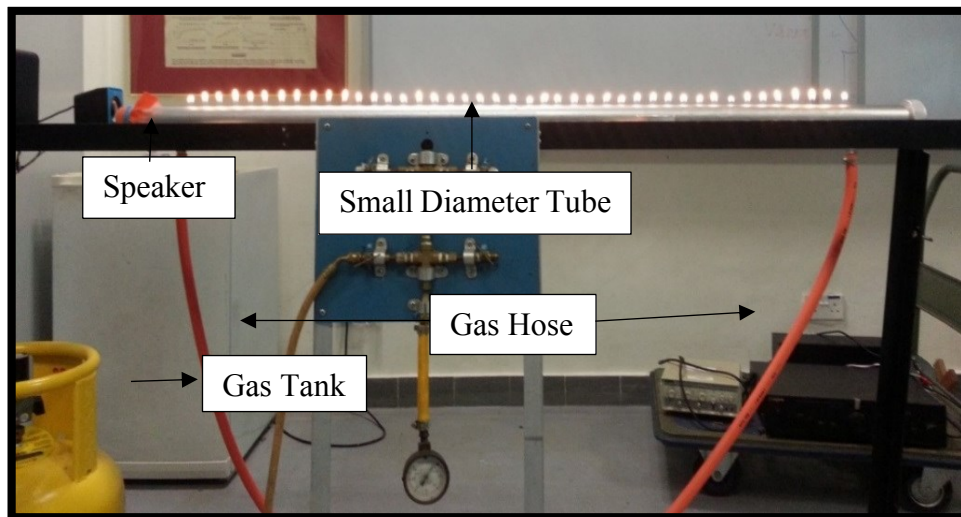


Figure 3.5: Apparatus Setup for Small Diameter Tube

The other Ruben's tube is also made from cast iron but slightly longer and has bigger diameter tube. It has length of 1.30 m and a diameter of 8.16 cm. It also will be measuring out of distance of 10 cm from each end of the tube. Then, it will be drill 43 holes in a line each a distance of one inch apart from each other with the diameter of each hole being two mm around as shown in Figure 3.6. Small diameter for hole chosen to prevent loss while using of gas during the experiment.

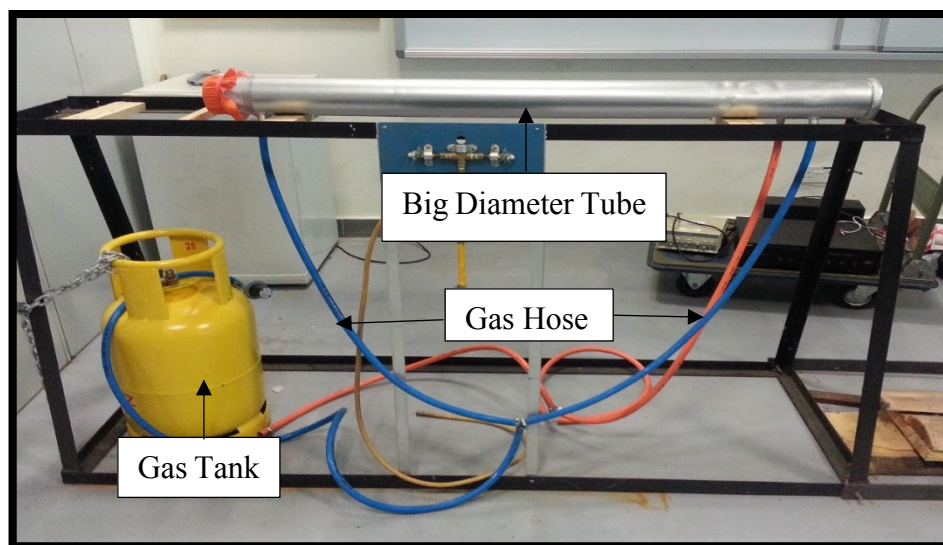


Figure 3.6: Apparatus Setup for Big Diameter Tube

After this, two holes drilled below from the line of holes for each type of material Ruben's tube roughly 10 cm away from each end. These holes were 6 mm around. From this point one closed end of the tube with a metal cap and soldered it shut. Then, took two brass fitting and placed them in the 6 mm holes. These too were soldered to ensure a tight seal. Then sealed one end with metal cap with small holes at the middle of it to allowed sound moves inside the tube. Next step in construction was taking a gas tube and cutting it into three sections. Two hoses stemmed from each brass fitting and a third to the gas source.

All three hoses were connected by a t-connector. Both experiment concept is same but the different is the small and big diameter of the tube. Basic experimental concept can be found in Figure 3.7. After the construction came to assembly, speaker will be mounted onto a base where the position speaker is mounted directly in front of the diaphragm end of the tube. The speaker is connected to an amplifier and a wave function generator.

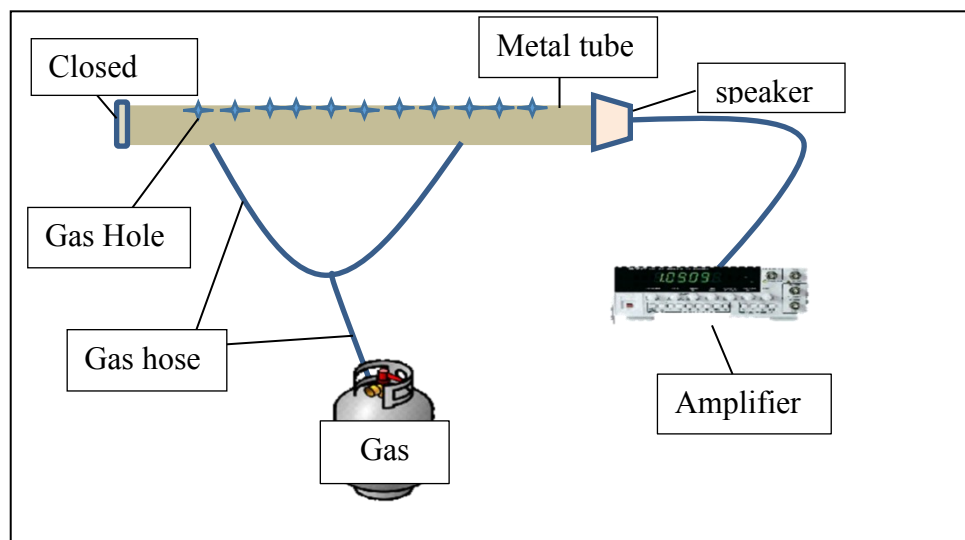


Figure 3.7: Experiment Concept for the Experiment

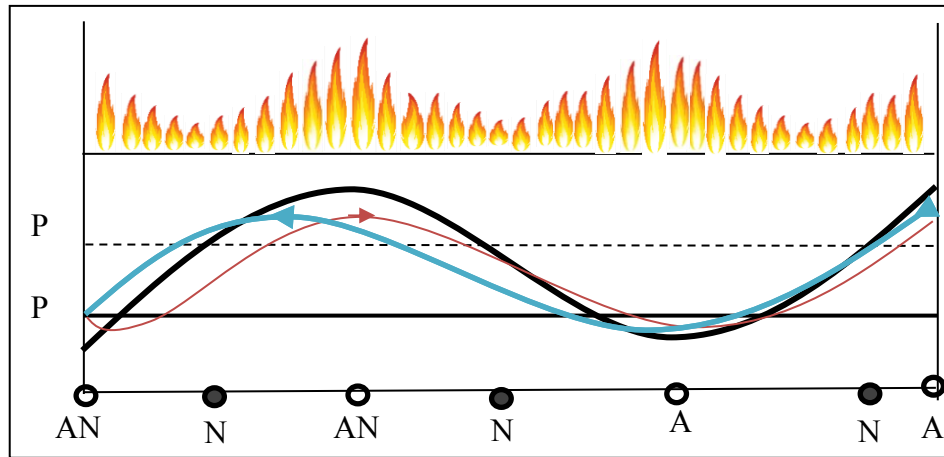


Figure 3.8: Schematic Diagram of Nodes and Antinodes

Figure 3.8 shows the schematic diagram of nodes and antinodes. Firstly, the tube is light up. Then, it starts with the introduction of the sinusoidal sound waves from the speaker to the tube. Later, the pressure waves travel down through the tube and reflect off the metal cap and travel back. At certain point along the tube, high pressure peak leaving the speaker will consistently meet up with a low-pressure peak returning from cap.

Both high and low pressure will be cancelling each other out, leaving the pressure continually at P_T which is called as pressure node (N). At other locations high pressure peaks combine at times and, at other times, low pressure through combine, creating what will call as antinodes (AN). The actual pressure felt down the tube is the sum of the waves leaving and returning to the speaker, and this sum creates a standing wave.

3.10 Experiment User Input

Speed of sound inside the tube with the condition of dry air at 20°C is 343.20 m/s for air and 249.51 m/s for propane.

Table 3.2: User Inputs for Experiment

Descriptions	Big	Small
1. Tube diameter	8.16 cm	4 cm
2. Hole spacing distance	2.5 cm	2.5 cm
3. Total hole for tube	43	43
4. Tube length	1.3 m	1.3 m
5. Thickness of the tube	0.3 cm	0.3 cm

3.11 Calculation of Data

This section consists of formula and data needed in calculation for result analysis. It used to calculate percentage of error, estimated frequency and speed of sound for this research study.

➤ **Percentage Error;**

$$\text{Percentage Error} = \frac{[Measure - Actual]}{Actual} \times 100\%$$

➤ **Room Temperature:** 27 °C

➤ **Speed of Sound for Dry Air at 20 °C:** Air = 342.93 m/s; Propane = 249.51 m/s

➤ **Speed of Sound for Frequency:** $v = \lambda f$

➤ **Tube Length:** Small Diameter Tube: 1.30 meter

Big Diameter Tube: 1.33 meters

➤ **Wavelength:** $\frac{4L}{n}$

➤ **Estimated Frequency:** $\frac{nv}{4L}$

Where; n: No of harmonic

L: Length of tube

v: Speed of sound

➤ **Control Variable:** Amplitude= 0.8

3.12 Experiment Testing Using Frequency Generator

Experiment setup for using frequency generator can be shown in Figure 3.9. It is based on manual setup where the researcher used frequency generator to control the frequency inside the tube.

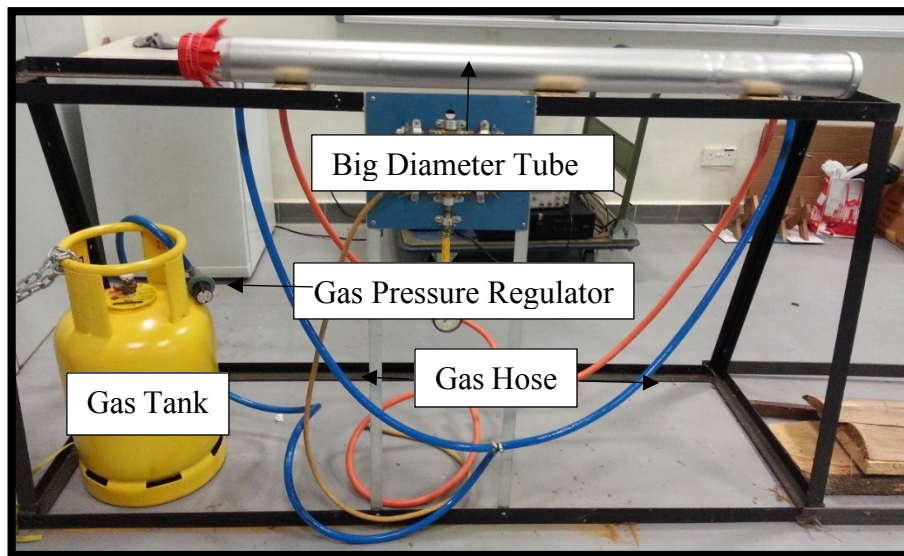


Figure 3.9: Experiment Setup of Ruben's Tube in the Laboratory

3.13 Experiment Testing Using Software

This experiment using software Audacity Frequency Generator version 2.1.3 to control the frequency produce in the experiment. The amplitude, pressure and temperature are kept constant to make it easier to collect the data and to make comparison. The speed of sound inside the tube can be collected using the software.

3.14 Variables in the Experiment

Various type of variable will have different effect on this experiment. There are independent, dependent and control variable. For this experiment, the only independent variable is frequency.

Then, frequency affects the dependent variable when the standing waves is generated. Apart from that, there are also control variable need to be taken care during the experiment such as gas pressure, room temperature and production of nodes and antinodes.

3.14.1 Gas Pressure

This experiment used two types of gas air and propane. It has direct effect on the calculation of the data due to different molecular mass. Molecular mass for dry air is 0.029 kg/mol and propane is 0.0441 kg/mol. Experiment is done in acoustic laboratory without any current of air. Windows and air conditionings keep closed to make sure the standing waves produced successfully. At the beginning of the experiment, some of the trials have failed due to standing waves does not produced. However, after few times adjusting the gas pressure standing waves are produces successfully. This experiment has been assumed to have the same gas pressure to work for different frequencies and it kept constant during the whole experiment.

3.14.2 Room Temperature

Each types of gas have different speed of gas at temperature 20 °C. Dry air at 20 °C has speed of gas of 343.20 m/s while propane at the same temperature has speed of gas 249.51 m/s. This experiment is held in acoustic laboratory hence, temperature would have an impact on the calculations. By using equation (10) and (11) the speed of gas can be found.

$$\lambda = \frac{4L}{n} \quad \text{Equation (10)}$$

$$v = \lambda f \quad \text{Equation (11)}$$

Even though the room temperature kept constant in this experiment, but it might be slightly differences since the fire is used. Therefore, the temperature is controlled each trial to overcome this problem.

3.14.3 Production of Nodes and Antinodes

When the frequency is increased the wavelength of the wave decrease hence, the number of nodes and antinodes increase. Since the tube is one closed end, the number of nodes and antinodes produces during the experiment are same as shown in Figure 3.10.

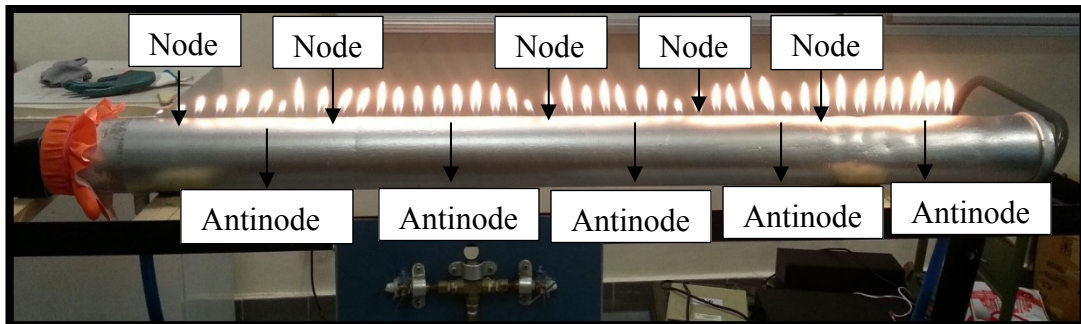


Figure 3.10: Number of Nodes and Antinodes Produces are Same

3.15 Summary

This chapter provides the framework for method of conducting this research study and the process to develop graph for result analysis. Also, this serve as planning stage for data collection and result analysis. Hence, the analyzed data is presented in the next chapter along with the discussion of data obtained. This chapter gives an overall summary on the procedure of how the research study is conducted.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

There are many interesting experiments that have been done years ago. Such an experience has lead the researcher to investigate the Ruben's Tube which has been come across to in a demonstration via the internet by chance. Watching demonstration was not as much as satisfactory for the researcher as other people. Therefore, the researcher decided to experiment the sound wave with other ways of demonstration which can attract people's attention and improve the quality of teaching.

Sound generates some kind of pressure. That can be understood by the application of a loudspeaker. When the frequency of the given sound changes suddenly and when it is very high as a value of the frequency, the membrane of the loudspeakers would move outwards. This phenomenon happens mainly due to the sudden frequency change on the sound waves. Despite a lot of peoples can watch the event in their daily life, they may not know the reason for it.

4.2 Air Gas for Small Diameter Tube

Table 4.1 shows the result analysis of air gas for small diameter tube. It shows wavelength and actual frequency for the best standing waves during the experiment. It also shows no percentage error and speed of sound for 1st harmonic due to difficult to find the peak of graph while using the software Audacity. The sin wave graph could not form clearly during the 1st harmonic. Therefore, it is hard to choose the actual frequency for it. This might due to low vibration of sin wave occurred inside the tube that make it difficult to detect the peak.

Table 4.1: Result Analysis for Air Gas (Small Diameter)

Harmonic No.	Wavelength (m)	Estimated Frequency (Hz)	Actual Frequency for the Best Standing Waves (Hz)	Percentage Error (%)	Speed of sound (m/s)
1	5.200	65.948	No peak	-	-
3	1.733	197.844	140	41.317	242.67
5	1.040	329.740	234	40.915	243.36
7	0.743	461.637	330	39.890	245.14
9	0.578	593.533	429	38.353	247.87
11	0.473	725.429	530	36.873	250.55

Figure 4.1 shows the first harmonic for air gas happen inside the small diameter tube. Nevertheless, defined sinusoidal pattern were difficult to find using the Audacity. It might due to low vibration of sin wave occurred inside the tube.

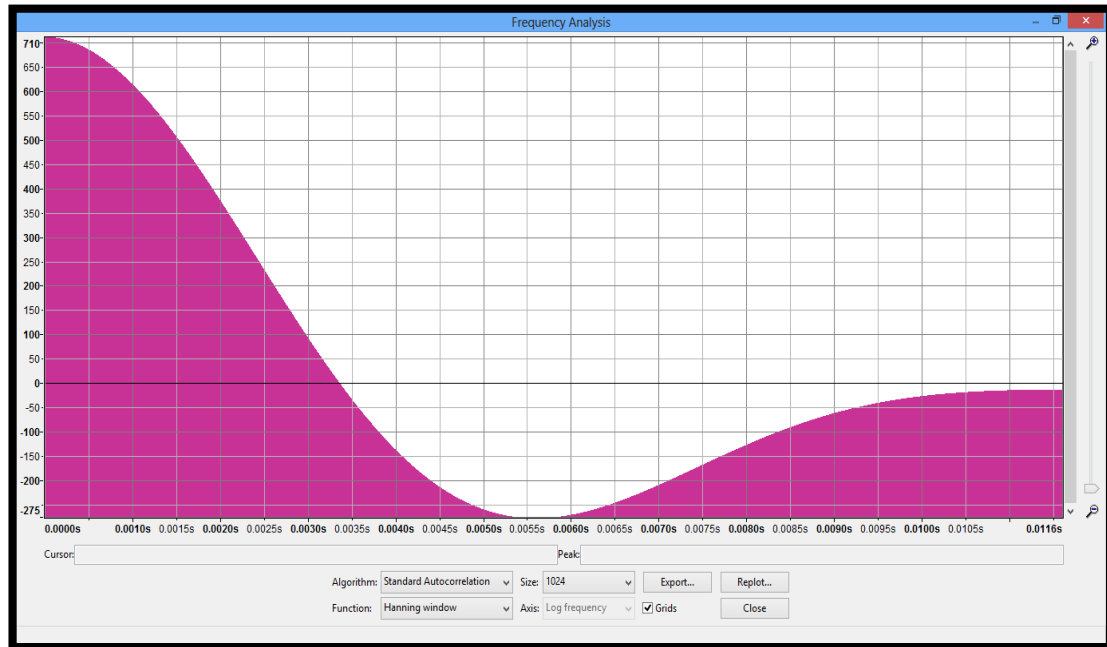


Figure 4.1: The First Harmonic in Small Diameter Tube

During the 3rd harmonic, the pattern of sin wave started to form. Figure 4.2 shows the sinusoidal pattern are able to formed with peak at 140 Hz. However, the production of nodes and antinodes still not form clearly.

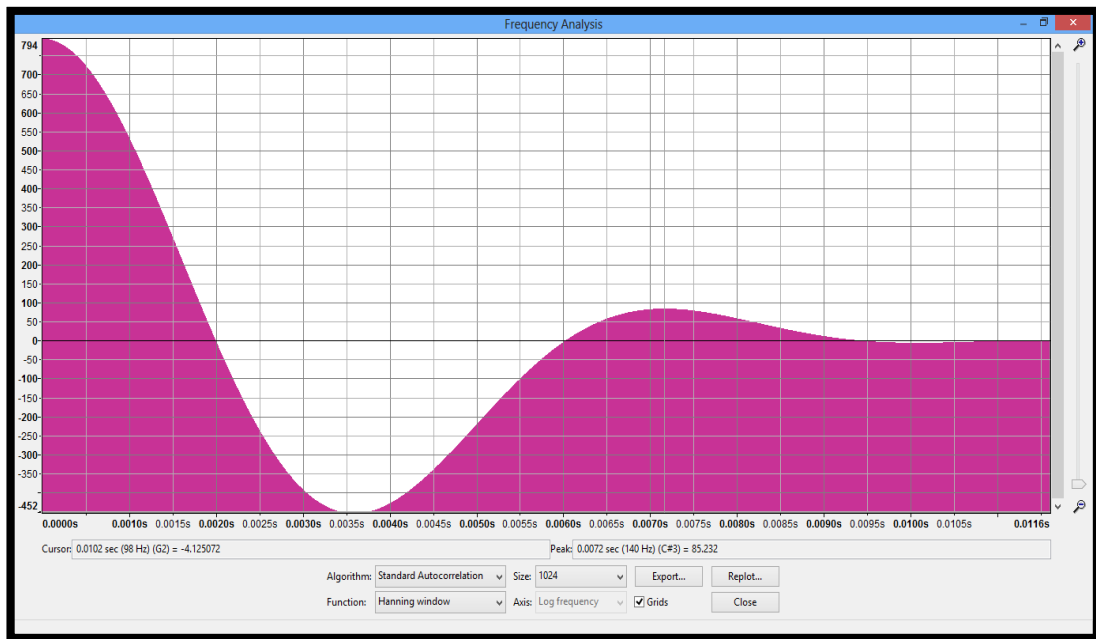


Figure 4.2: The Third Harmonic in Small Diameter Tube

The fifth harmonic in Figure 4.3 shows slightly better form of sin wave with peak at 234 Hz. When the frequency increase, the wavelength will decrease. However, the production of nodes and antinodes will increase.

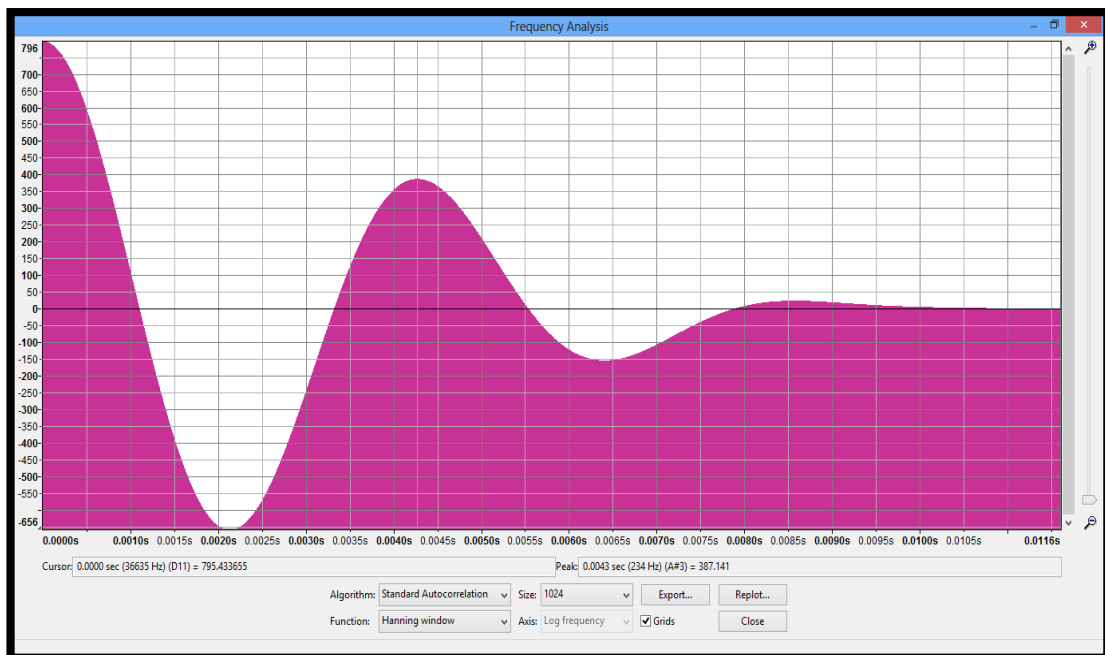


Figure 4.3: The Fifth Harmonic in Small Diameter Tube

The seventh harmonic in Figure 4.4 for air shows better shape of graph with peak at 330 Hz. The peak of the graph could be detected much easier at higher frequency. The sin wave pattern also has become clearer.

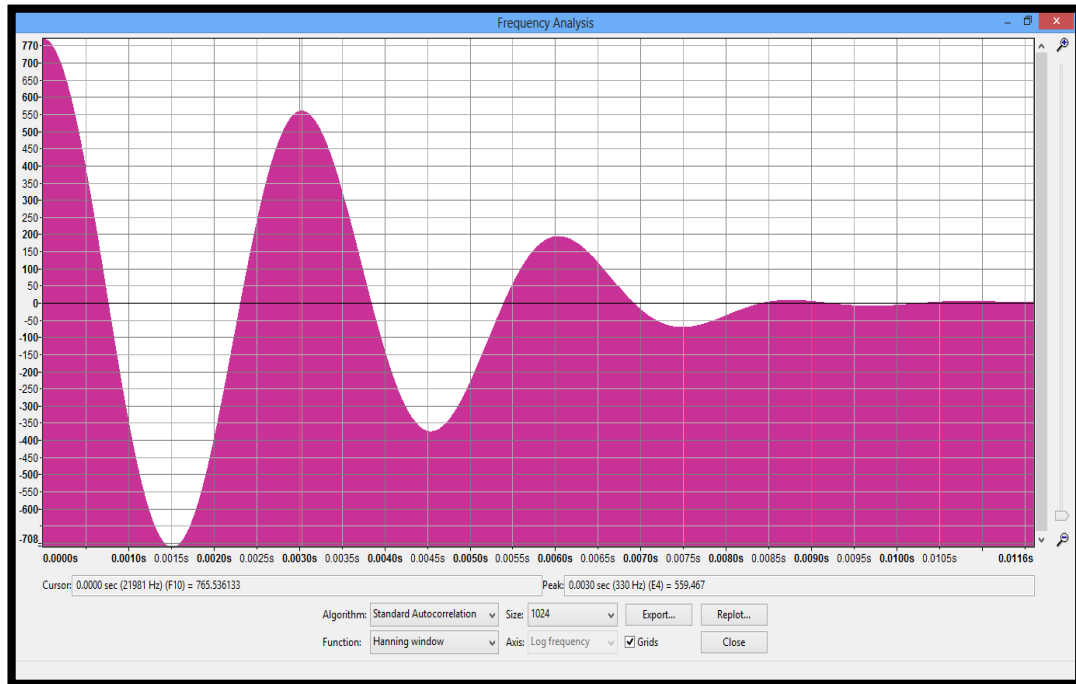


Figure 4.4: The Seventh Harmonic in Small Diameter Tube

The ninth harmonic in Figure 4.5 has clear peaks at valleys at 429 Hz. However, the shape of graph still has a lot of ridges. The wavelength of the graph decreased when the number of nodes and antinodes increased.

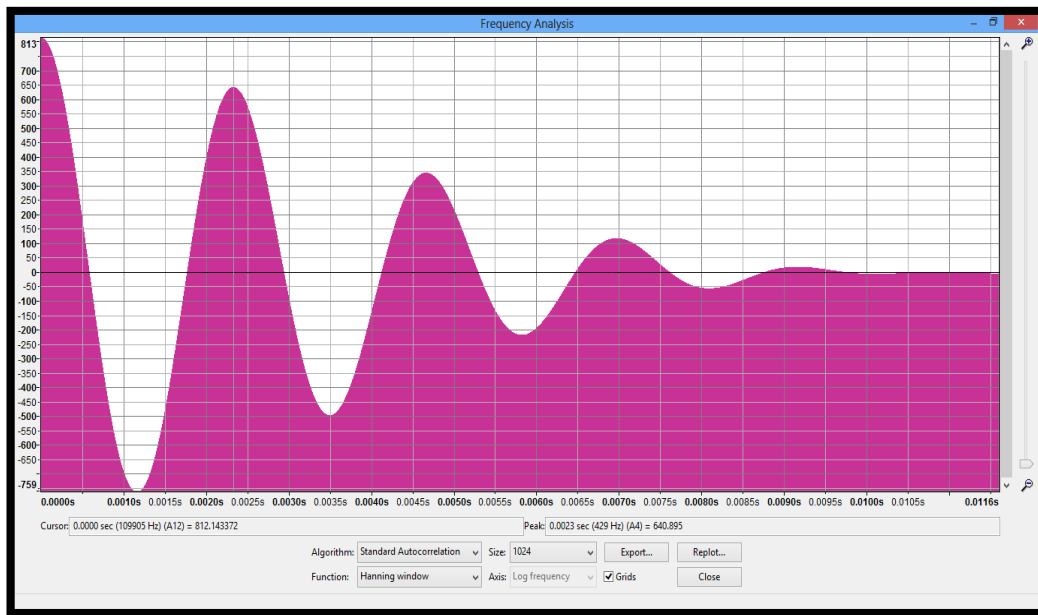


Figure 4.5: The Ninth Harmonic in Small Diameter Tube

The eleventh harmonic in Figure 4.6 produced the best result on showing the sinusoidal pattern. It shows better shape of sine wave with the peak at 530 Hz. The sin wave can detect easily after increase the frequency. Figure 4.6 also shows the wavelength decrease when the production of nodes and antinodes increase.

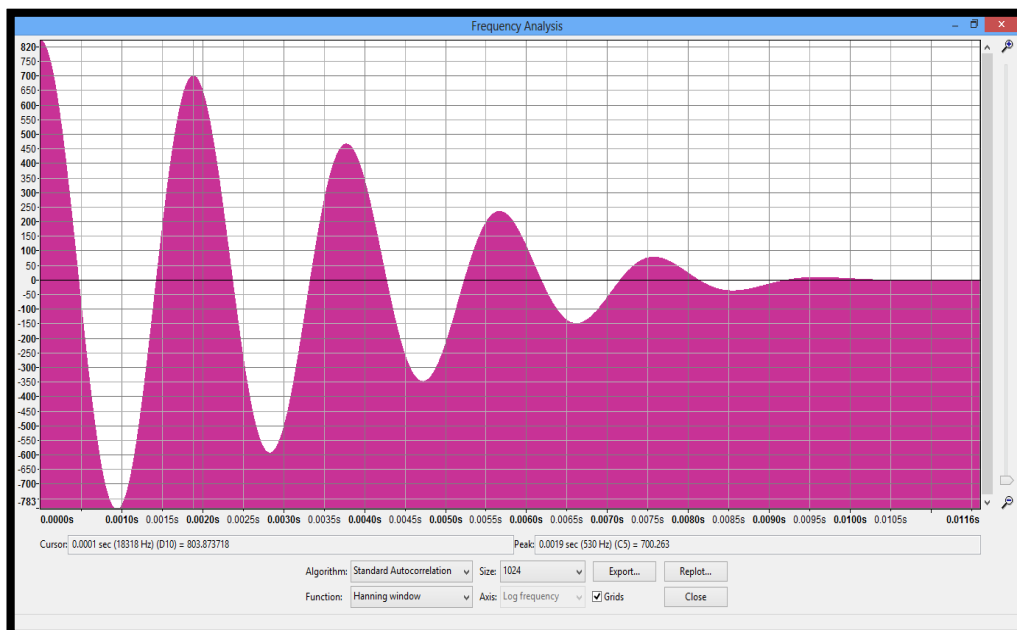


Figure 4.6: The Eleventh Harmonic in Small Diameter Tube

4.3 Air Gas for Big Diameter Tube

Table 4.2 shows the result analysis of air gas for big diameter tube. It shows wavelength and actual frequency for the best standing waves during the experiment. It also shows no percentage error and speed of sound during the 1st harmonic due to difficult to find the peak while using the software Audacity. The software could not detect the peak for 1st harmonic might due to low vibration of sin wave occurred inside the tube. Therefore, no actual frequency for the best standing wave recorded for the 1st harmonic.

Table 4.2: Result Analysis for Air Gas (Big Diameter)

Harmonic No.	Wavelength (m)	Estimated Frequency (Hz)	Actual Frequency for the Best Standing Waves (Hz)	Percentage Error (%)	Speed of Sound (m/s)
1	5.320	64.461	No peak	-	-
3	1.773	193.382	163	18.639	289.05
5	1.064	322.303	255	26.393	271.32
7	0.760	451.224	353	27.825	268.28
9	0.591	580.145	452	28.351	267.18
11	0.484	709.066	552	28.459	266.97

Figure 4.7 shows the 1st harmonic for air gas with big diameter tube. However, it is difficult to find sinusoidal pattern and it shows no peak when using the software Audacity. It might due to low vibration of sin wave produced inside the tube.

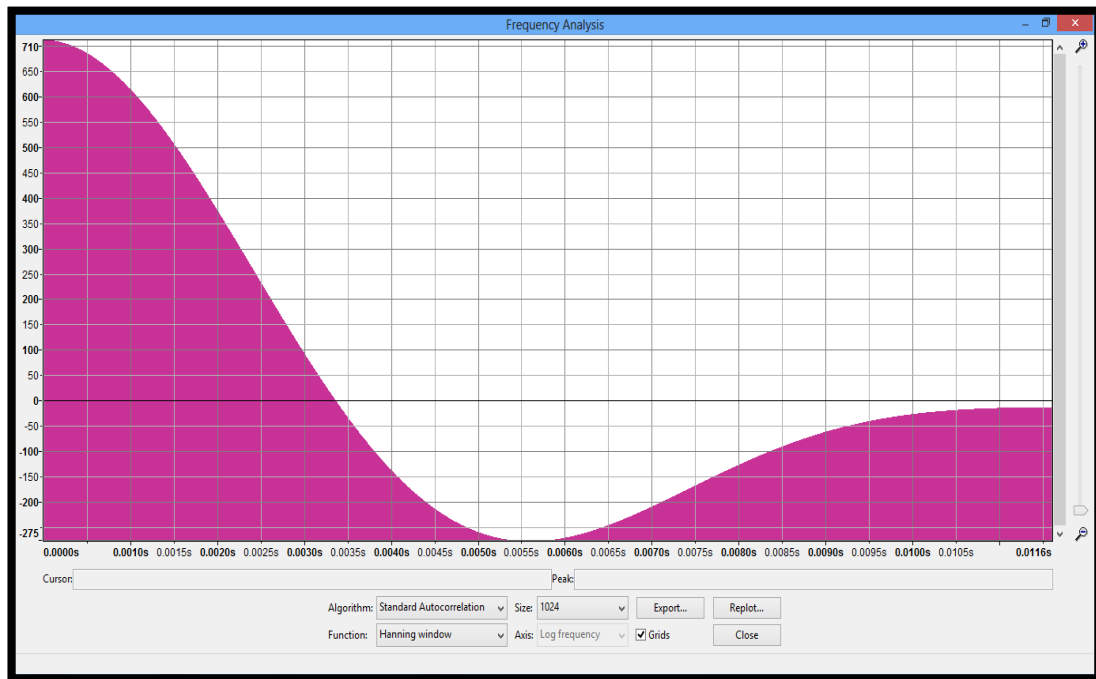


Figure 4.7: The First Harmonic in Big Diameter Tube

The 3rd harmonic in Figure 4.8 starting to show sinusoidal pattern with the peak at 163 Hz. The pattern of graph starting to show the sin wave produced inside the big diameter tube. However, the production of nodes and antinodes still could not form clearly.

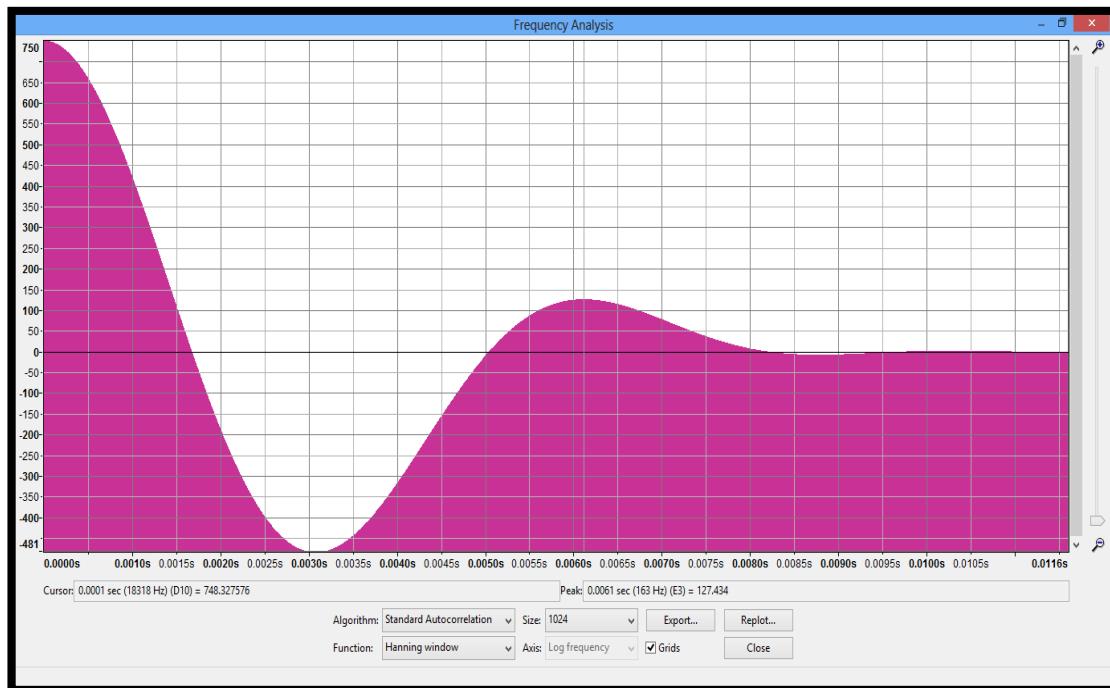


Figure 4.8: The Third Harmonic in Big Diameter Tube

The 5th harmonic in Figure 4.9 shows slightly better form of graph with peak at 255 Hz. It shows that big diameter tube has better stability than the small diameter tube.

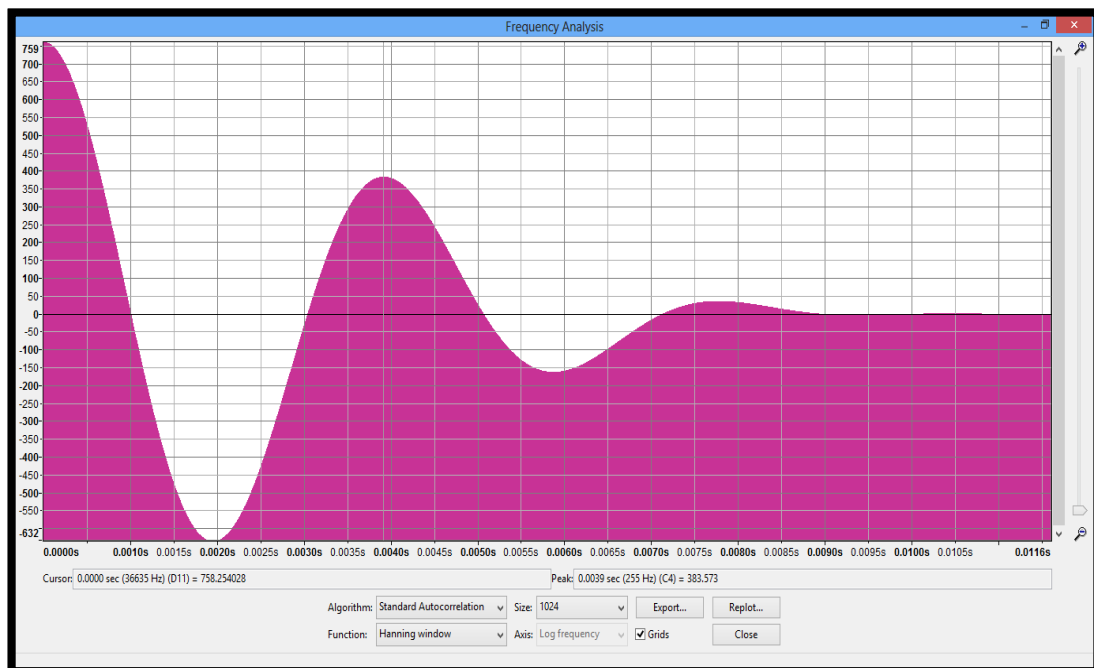


Figure 4.9: The Fifth Harmonic in Big Diameter Tube

The 7th harmonic in Figure 4.10 show better shape of graph with peak at 353 Hz. It has better form of sin wave than the small diameter tube. The bigger tube makes the propagation of velocity accelerates faster.

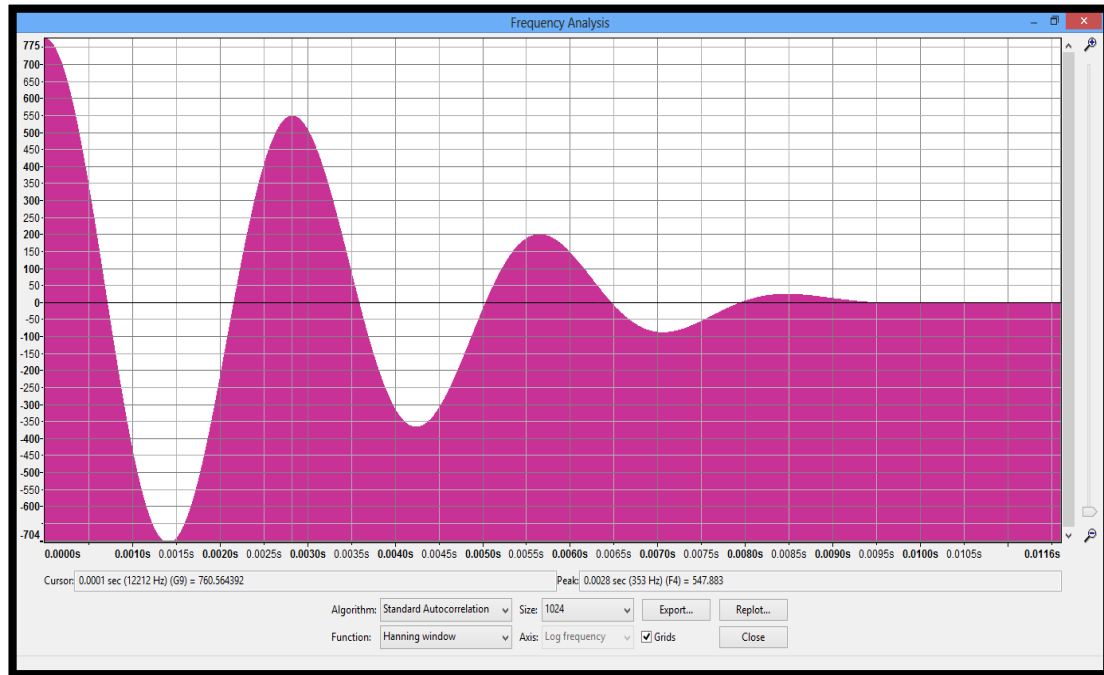


Figure 4.10: The Seventh Harmonic in Big Diameter Tube

The 9th harmonic in Figure 4.11 has clear peaks at 452 Hz. Nevertheless, the shape of graph still has a lot of ridges even though the researcher increases the frequency during the experiment. Besides, the best actual frequency for big diameter tubes a bit higher compare to small diameter tube.

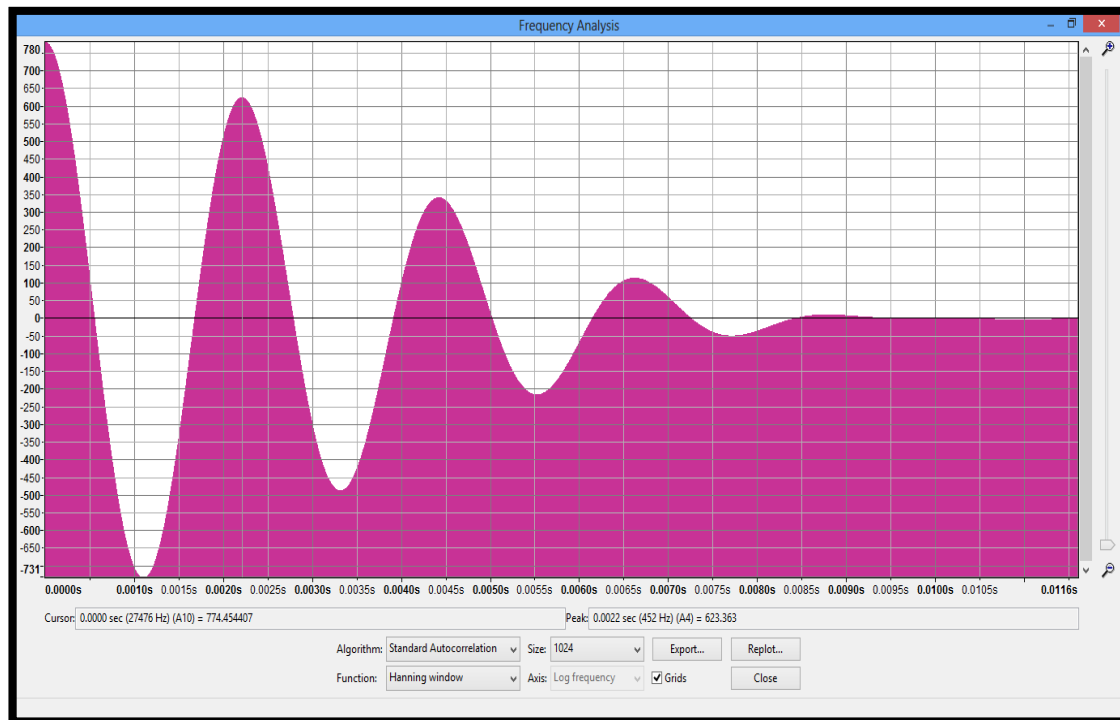


Figure 4.11: The Ninth Harmonic in Big Diameter Tube

Above all, the 11th harmonic in Figure 4.12 has the best result in showing the sinusoidal pattern with the peak at 552 Hz. The wavelength decreases when increase the frequency and the production of nodes and antinodes also increased at 11th harmonic. The bigger diameter tube also optimizes the heat transfer inside the tube.

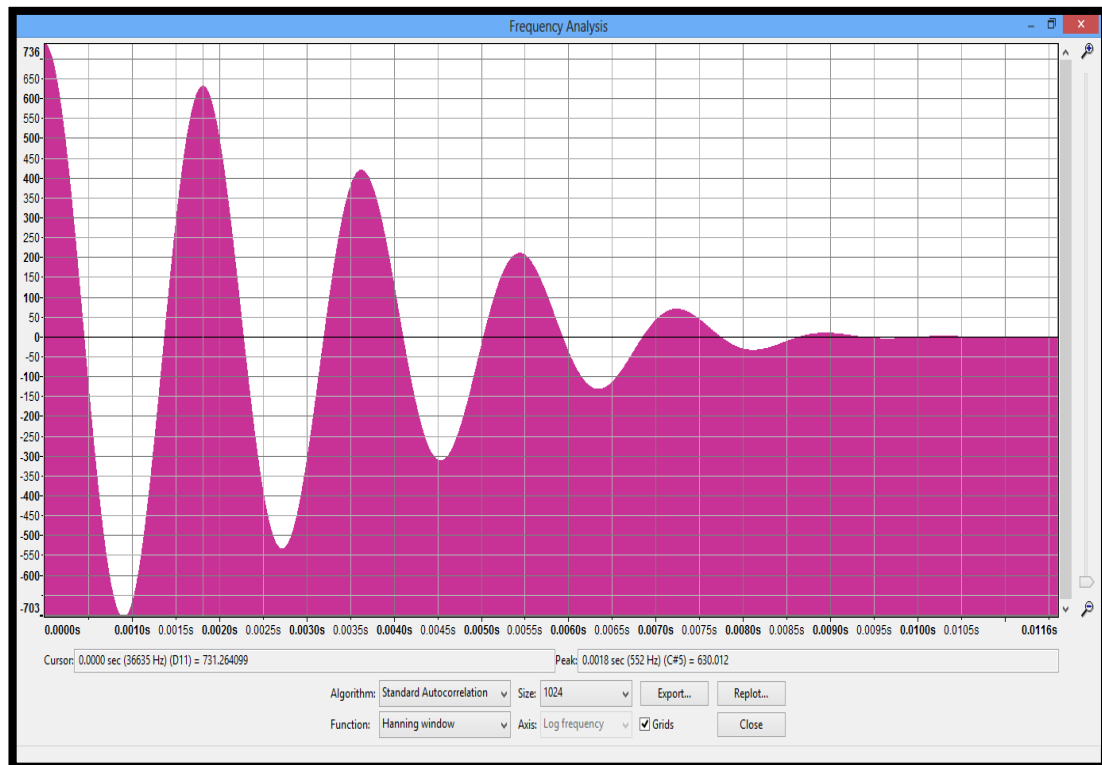


Figure 4.12: The Eleventh Harmonic in Big Diameter Tube

4.4 Propane Gas for Small Diameter Tube

Table 4.3 shows the result analysis of propane gas for small diameter tube. It shows the wavelength and actual frequency for the best standing wave during the experiment. It also shows no percentage error and speed of sound for the 1st harmonic due to difficult to find the peak of graph while using the software Audacity. The software could not detect the peak of graph due to low vibration of sin wave occurred inside the tube. Hence, no actual frequency for the best standing wave and speed of sound inside the tube recorded for the 1st harmonic.

Table 4.3: Result Analysis for Propane Gas (Small Diameter)

Harmonic No.	Wavelength (m)	Estimated Frequency (Hz)	Actual Frequency for the Best Standing Waves (Hz)	Percentage Error (%)	Speed of Sound (m/s)
1	5.200	47.983	No peak	-	-
3	1.733	143.948	113	27.388	195.87
5	1.040	239.913	206	16.463	214.24
7	0.743	335.879	304	10.487	225.83
9	0.578	431.844	402	7.424	232.27
11	0.473	527.810	503	4.932	237.78

Result analysis by using propane gas to show standing waves can be seen in Table 4.4. This experiment shows the result production of wave in the form of fire. The nodes and antinodes increase when increase the frequency. However, wavelength will decrease.

Table 4.4: Standing Waves Produced at Certain Frequency for Propane Gas (Small Diameter Tube)

Frequency (Hz)	Standing Waves Produces
50	This is the 1st harmonic for the small diameter tube. No peak was found using the Audacity even though the estimated frequency supposedly to be 47.98 Hz. The vibration of the sin wave is low and make it difficult to find the actual frequency. 

Table 4.4 continued

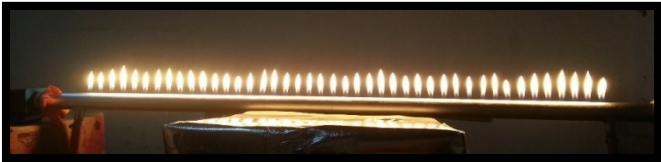
100	The peak for the 3rd harmonic is 113 Hz. However, the production of nodes and antinodes are not noticeable. 
200	The peak for the 5th harmonic is 206 Hz. The standing wave above the tube starting to show the nodes and antinodes clearly. 
300	The peak for the 7th harmonic is 304 Hz. There is some missing flame detected above the tube and one point of flame higher than others. This might due to small diameter tube effect the stability of flame production and decrease the resonance shift of the fire. 
400	The peak for 9th harmonic is 402 Hz. At this point, the wavelength decreases and the production of nodes and antinodes increase. 

Table 4.4 continued

500	The peak for the 11th harmonic is 503 Hz. The standing wave above the tube can be seen clearly compare to previous harmonic. 
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Figure 4.13 shows the frequency analysis for propane gas with small diameter tube by using the Audacity. In the 1st harmonic, defined sinusoidal pattern were difficult to find and there is no peak detected using Audacity. It might due to low production of sin wave and low flame propagation velocity produces inside the tube.

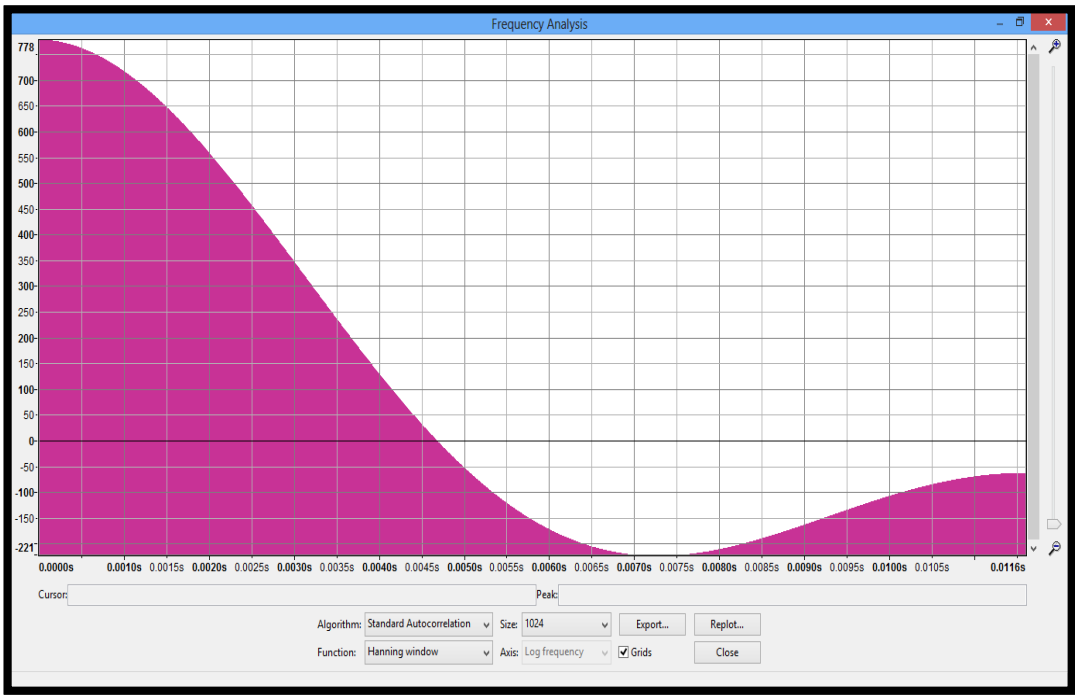


Figure 4.13: The First Harmonic in Small Diameter Tube

The 3rd harmonic in Figure 4.14 for propane gas has low peak compared with the air gas for small diameter tube. This is due to different molecular mass of the gas present. The sinusoidal pattern is able to show with peak at 113 Hz.

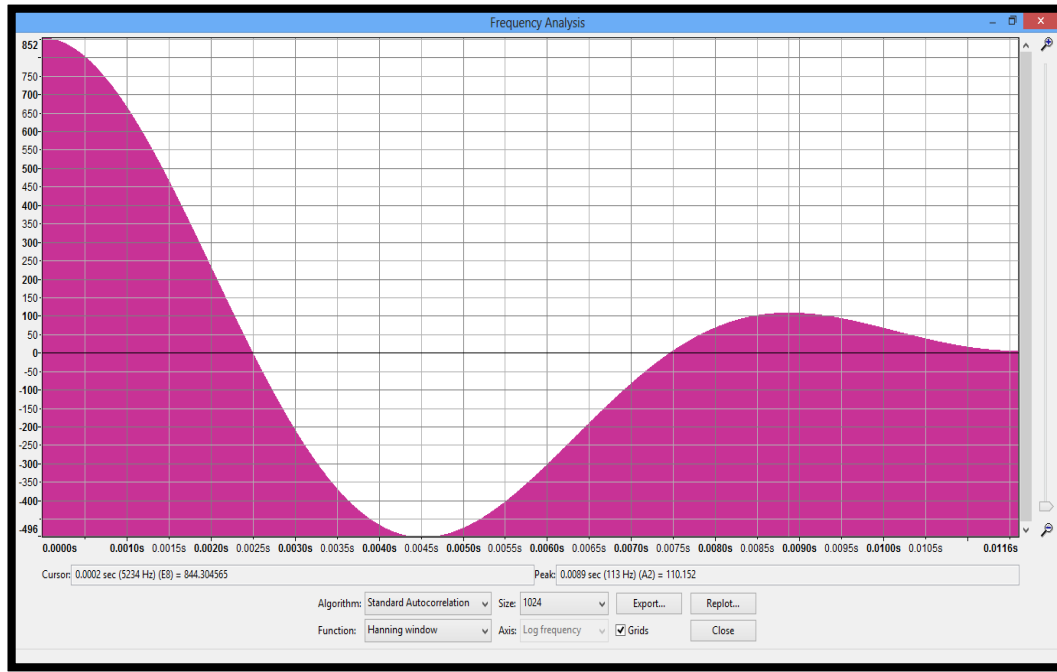


Figure 4.14: The Third Harmonic in Small Diameter Tube

The 5th harmonic in Figure 4.15 show slightly better form of graph with peak at 206 Hz. The sin wave slowly shows the pattern of graph inside the tube. When the frequency increases the wavelength will decrease.

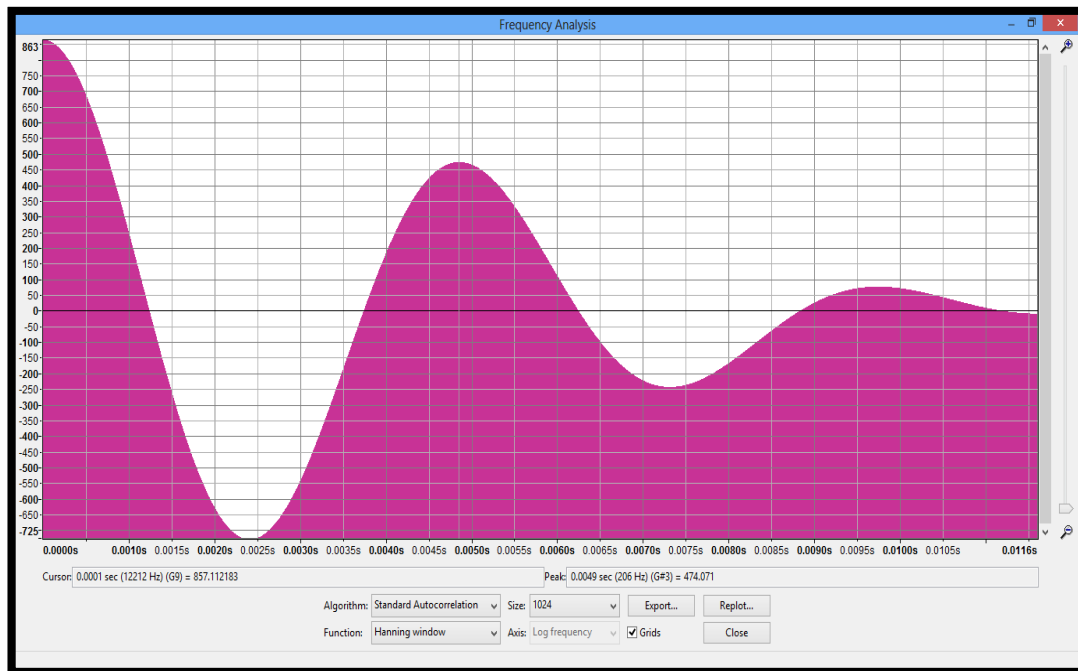


Figure 4.15: The Fifth Harmonic in Small Diameter Tube

The 7th harmonic in Figure 4.16 shows better shape of graph than the 5th harmonic with peak at 304 Hz. It starts to show the production of nodes and antinodes inside the tube.

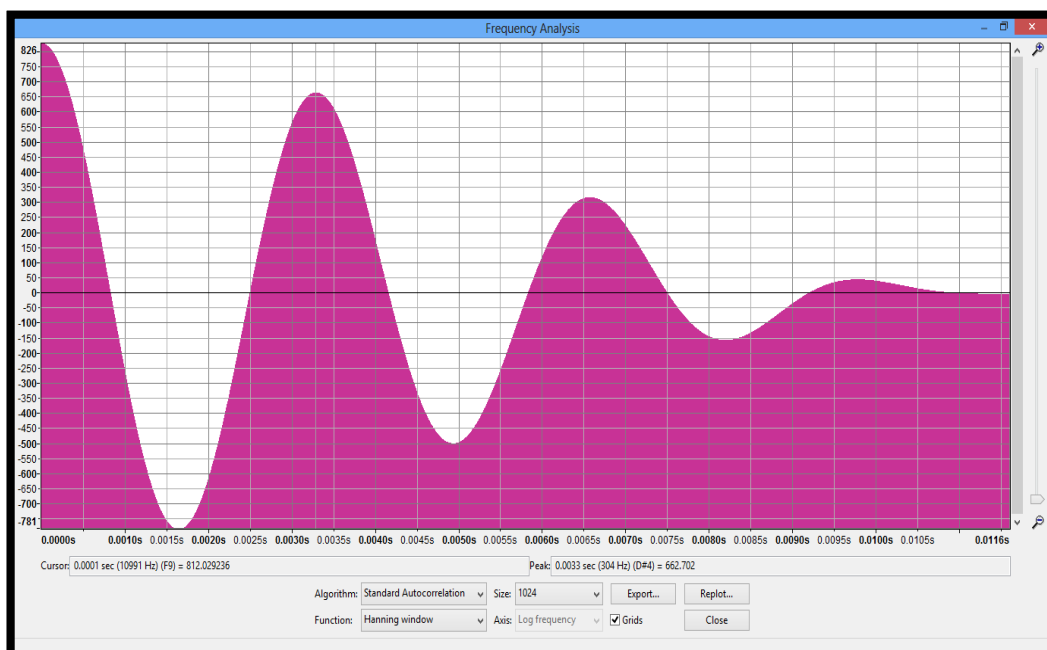


Figure 4.16: The Seventh Harmonic in Small Diameter Tube

There were clear peaks and valleys for the 9th harmonic in Figure 4.17. However, it still has a lot of ridges. The peak of graph shows value at 402 Hz.

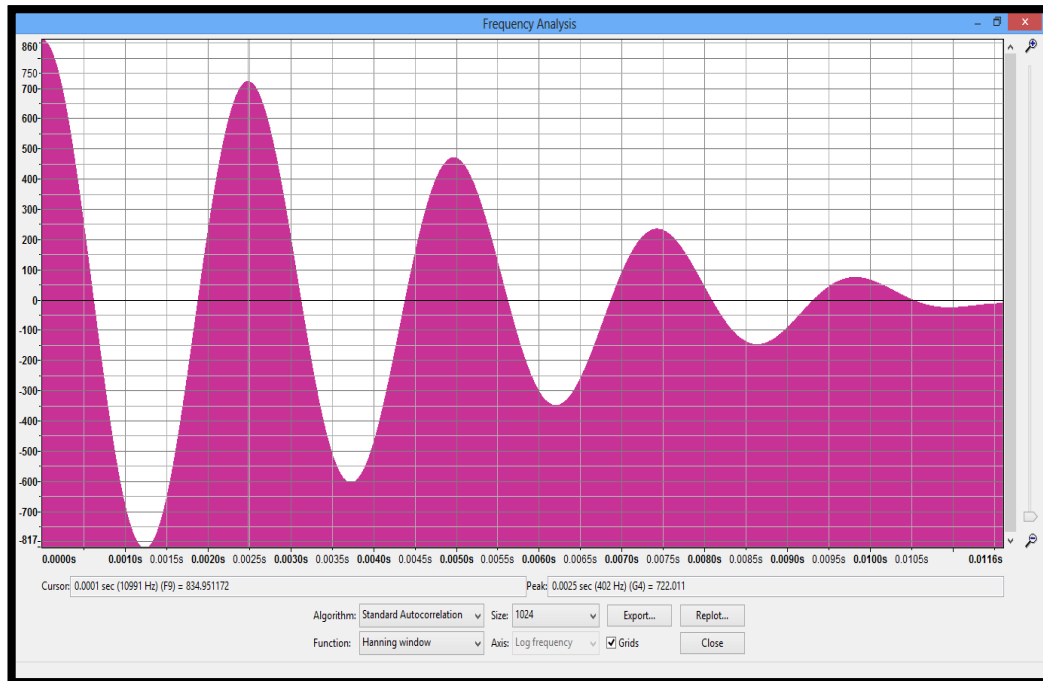


Figure 4.17: The Ninth Harmonic in Small Diameter Tube

The 11th harmonic in Figure 4.18 shows the best result with peak at 503 Hz. The pattern of sinusoidal wave also become clearer. The speed of sound for air increase when the frequency inside the tube is increased.

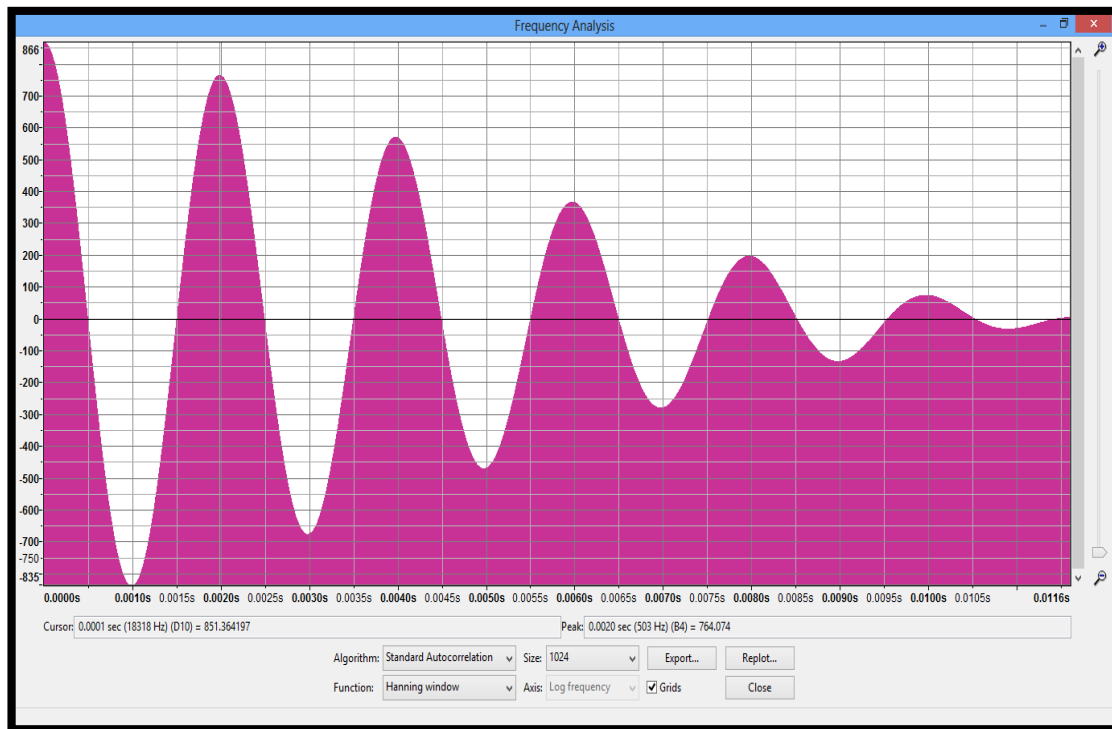


Figure 4.18: The Eleventh Harmonic in Small Diameter Tube

4.5 Propane Gas for Big Diameter Tube

Table 4.5 shows the result analysis of propane gas for big diameter tube. It shows the wavelength and actual frequency for the best standing waves during the experiment. It also shows no percentage error and speed of sound for the 1st harmonic due to difficult to find the peak of graph while using the software Audacity. Besides, this might due to low vibration of sin wave produces inside the tube and make it difficult to detect the peak. The speed of sound in propane gas for big diameter tube also near to theoretical value than the speed of sound in air gas. Both gases have different molecular mass.

Table 4.5: Result Analysis for Propane Gas (Big Diameter)

Harmonic No.	Wavelength (m)	Estimated Frequency (Hz)	Actual Frequency for the Best Standing Waves (Hz)	Percentage Error (%)	Speed of Sound (m/s)
1	5.320	46.900	No peak	-	-
3	1.773	140.701	159	11.509	281.96
5	1.064	234.502	253	7.311	269.19
7	0.760	328.303	351	6.466	266.76
9	0.591	422.103	450	6.199	266.00
11	0.484	515.904	549	6.028	265.52

This experiment conducted by using big diameter tube for propane gas. Big diameter tube shows better standing wave than the small diameter tube as shown in Table 4.6. The appearance of standing waves in the form of fire can be seen more clearly.

Table 4.6: Standing Waves Produced at Certain Frequency for Propane Gas (Big Diameter Tube)

Frequency (Hz)	Standing Waves Produces
50	This is the 1st harmonic for the big diameter tube. No peak was found using the Audacity even though the estimated frequency supposedly to be 46.9 Hz. The vibration of sin wave is low and makes it difficult to find the best standing wave for it. 

Table 4.6 continued

100	The peak for the 3rd harmonic is 159 Hz. A bit higher than the 3rd harmonic for the small diameter tube. The bigger tube diameter make flame accelerates faster. 
200	The peak for the 5th harmonic is 253 Hz. The production of nodes and antinodes can be seen clearly for the big diameter tube compare to smaller tube. 
300	The peak for the 7th is 351 Hz. All flame produces successfully above the tube. It shows that big diameter tube has better stability and better changes in flame shape. 

Table 4.6 continued

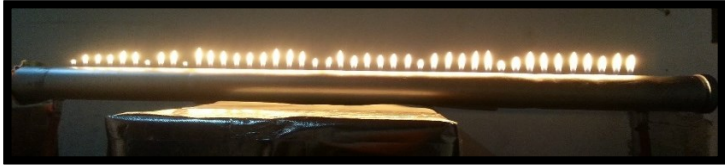
400	The peak for the 9th harmonic is 450 Hz. The frequency getting higher and increase the production of nodes and antinodes while the wavelength is decrease. It is found that the flame propagation velocity increase with the tube diameter. 
500	The peak for the 11th harmonic is 549 Hz. A bit higher when compare with the small diameter tube with the same number of harmonics. It also shows that big diameter tube has better changes in flame shape and has better stability of the integrated system. 

Figure 4.19 shows the frequency analysis for propane gas using big diameter tube. The 1st harmonic shows no peak for the graph and there was no shape of sinusoidal pattern. The gas particles move in slow motion and make it difficult to find the peak through Audacity. The nodes and antinodes also do not form clearly during the 1st harmonic.

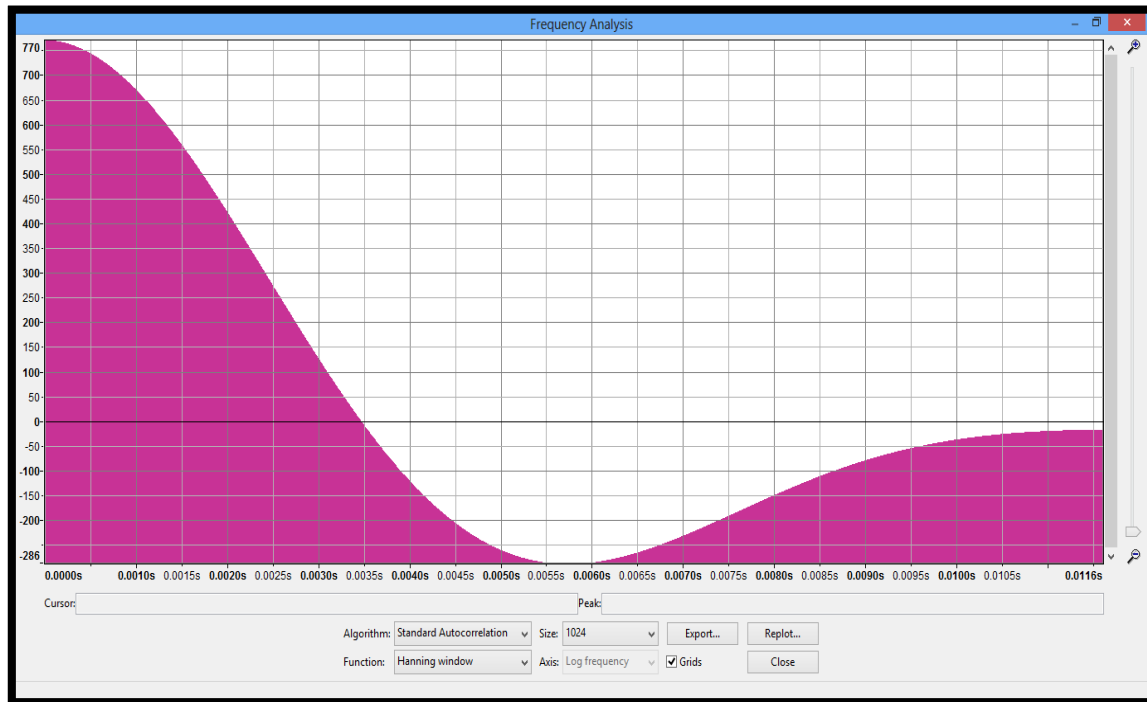


Figure 4.19: The First Harmonic in Big Diameter Tube

The 3rd harmonic in Figure 4.20 has higher peak than the smaller diameter tube which is 159 Hz. The sinusoidal start to form at the 3rd harmonic. The standing wave pattern start to show the sin wave produces inside the tube. However, only small sin wave pattern able to show at this stage.

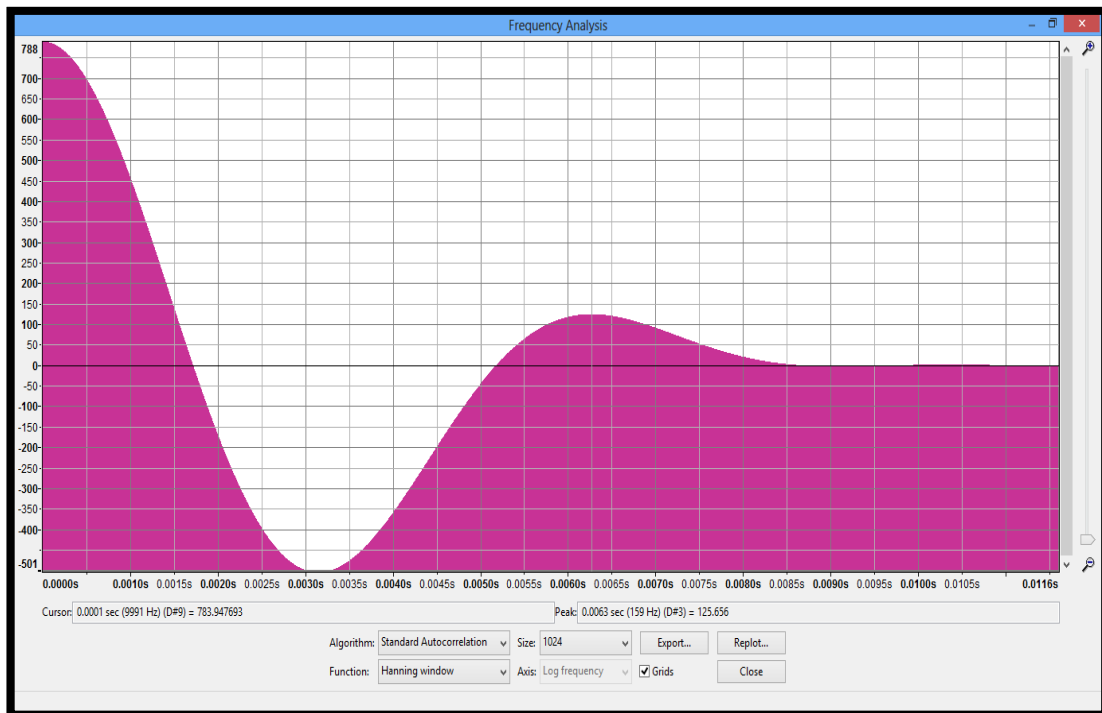


Figure 4.20: The Third Harmonic in Big Diameter Tube

The 5th harmonic in Figure 4.21 has better form of graph than the previous harmonic. The peak show at 253 Hz. The gas particles start to move vigorously inside the tube and standing wave above the tube start to form clearly.

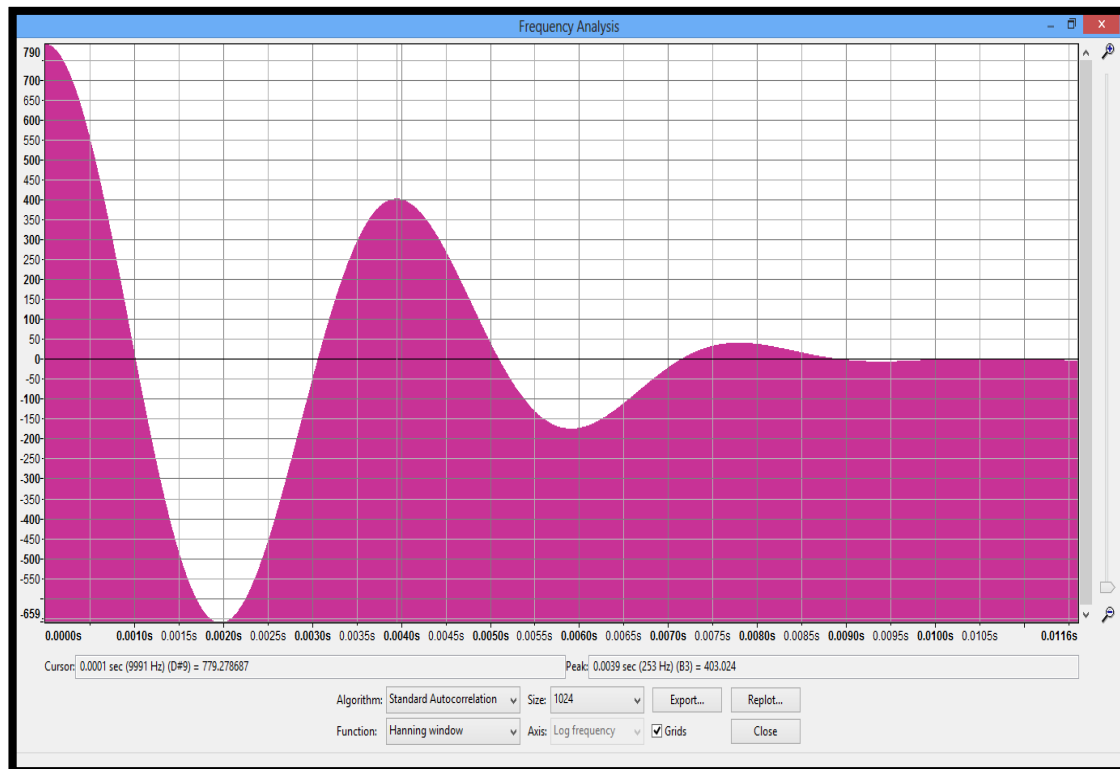


Figure 4.21: The Fifth Harmonic in Big Diameter Tube

The 7th harmonic in Figure 4.22 show slightly better form of sinusoidal pattern with peak at 351 Hz. The wavelength decreases and the production of nodes and antinodes increase with the number of harmonics.

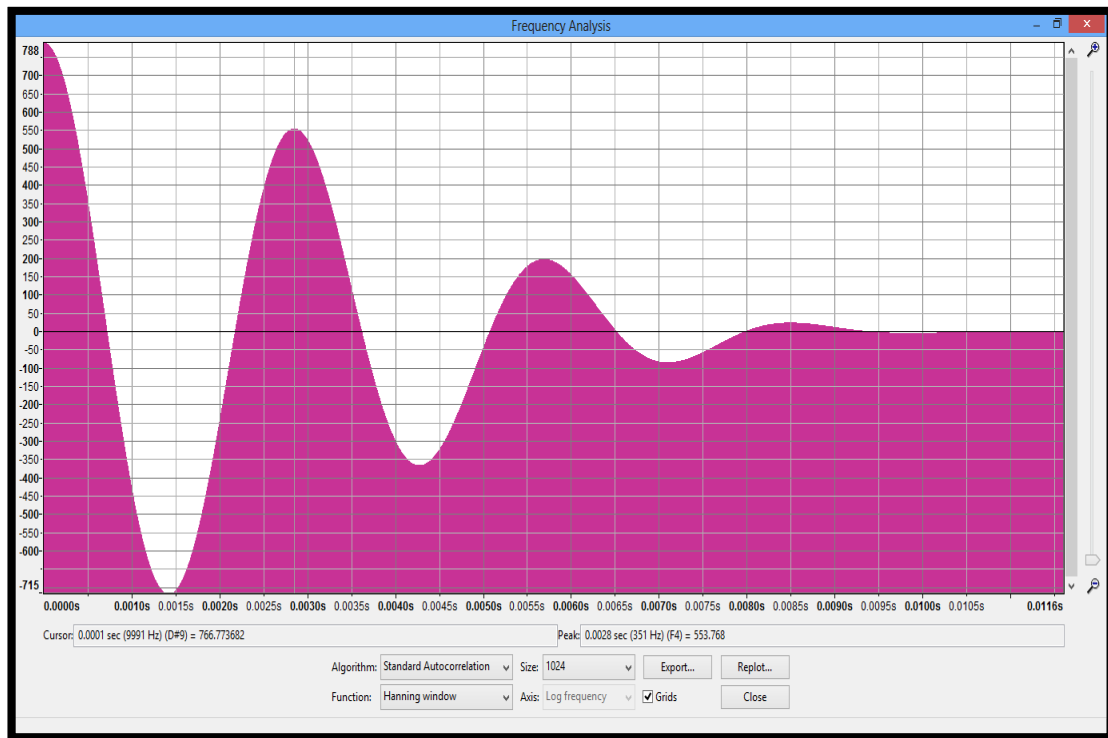


Figure 4.22: The Seventh Harmonic in Big Diameter Tube

The 9th harmonic in Figure 4.23 has peak at 450 Hz. Obviously, the sinusoidal pattern was clearer than the other harmonic before.

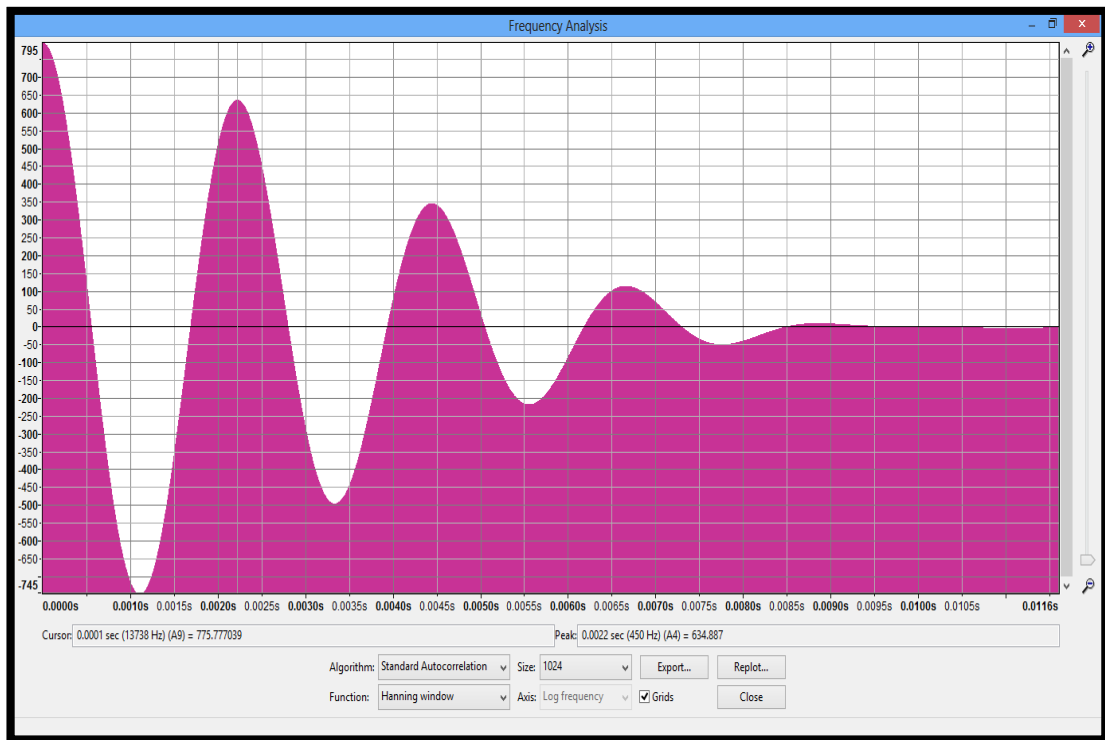


Figure 4.23: The Ninth Harmonic in Big Diameter Tube

The 11th harmonic in Figure 4.24 produced the best result showing the sinusoidal pattern. It has better shape with the peak at 549 Hz. The big diameter tube has better flame propagation velocity and make the flame accelerates faster. Besides, big diameter tube has better form of flame rather than small diameter tube.

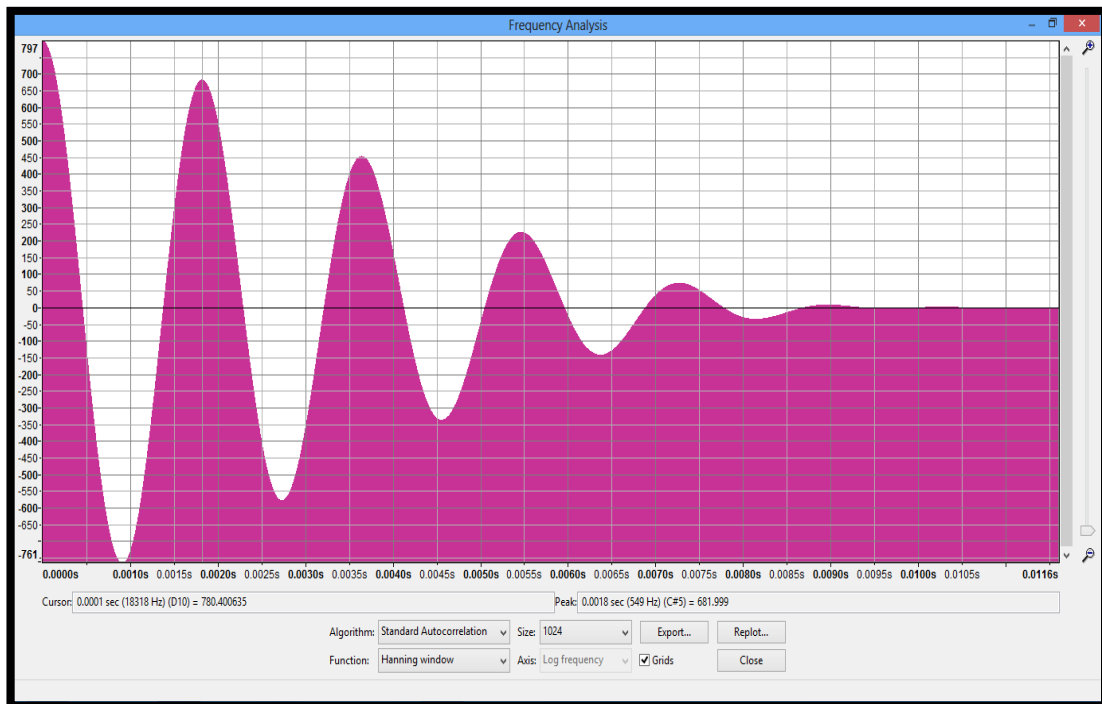


Figure 4.24: The Eleventh Harmonic in Big Diameter Tube

4.6 Graph Analysis

This section explains the result in the experiment in the form of graph. Comparison has been made to compare each result for each criterion. Therefore, it is easier to see the difference between each result.

1. Air Gas: Actual Frequency at Small Diameter Tube and Big Diameter Tube

Figure 4.25 shows the actual frequency in small diameter tube and big diameter tube for air gas. The green line indicates actual frequency in big diameter tube and the blue line indicates actual frequency in small diameter tube. This experiment does not use fire therefore, it is difficult to find the best standing wave. Actual frequency in small diameter tube is smaller than actual frequency in big diameter tube. The difference might be a result of the different size of diameter tube.

Besides, big diameter tube increases the propagation of velocity rather than small diameter tube. Therefore, the highest actual frequency for big diameter tube is 552 Hz while for the small diameter tube is 530 Hz.

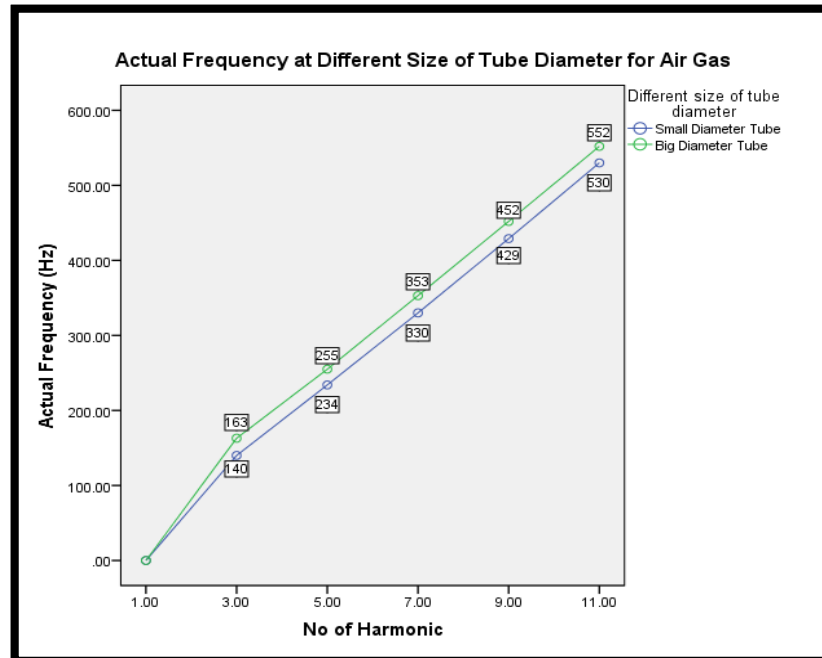


Figure 4.25: Actual Frequency at Small and Big Diameter Tube for Air Gas

2. Propane Gas: Actual Frequency at Small Diameter Tube and Big Diameter Tube

Figure 4.26 shows the actual frequency in small diameter tube and big diameter tube for propane gas. The green line indicates actual frequency in big diameter tube whereas the blue line indicates actual frequency in small diameter tube. This experiment used fire to show the best standing wave inside the tube. Overall, big diameter tube has higher actual frequency than small diameter tube. This is due to big diameter tube has better performance on the flame propagation than the smaller tube. The highest actual frequency for big diameter tube is 549 Hz while for the small diameter tube is 503 Hz. Apart from that, big diameter tube has better changes in flame shape than small diameter tube. It increases in burning surface area and effectiveness of the experiment.

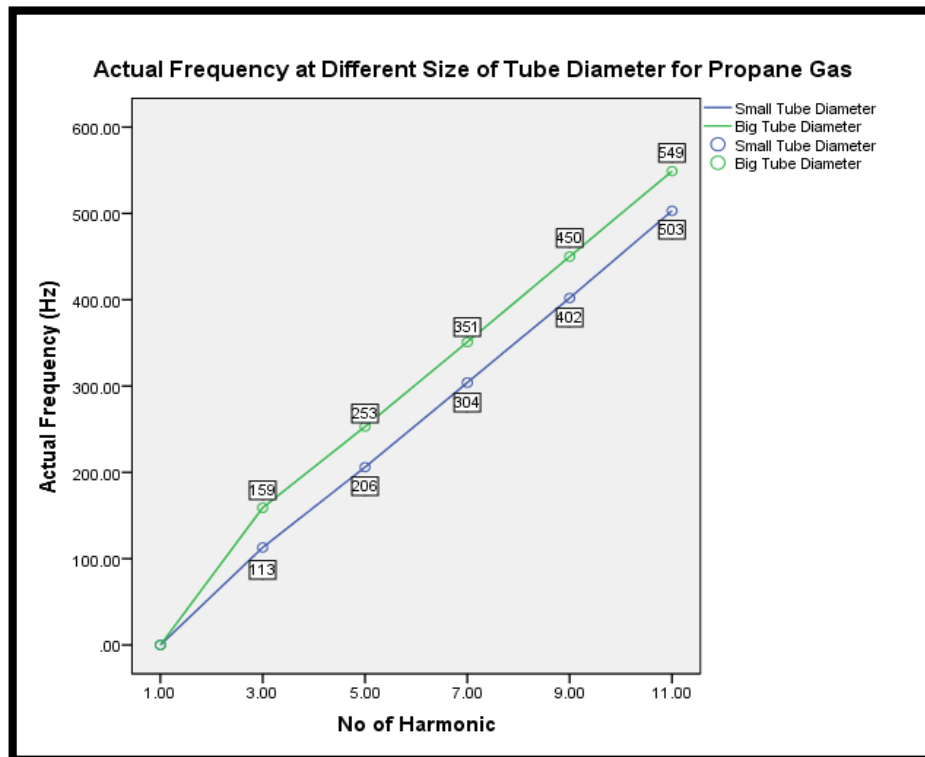


Figure 4.26: Actual Frequency at Small and Big Diameter Tube for Propane Gas

3. Air Gas: Estimated Frequency versus Actual Frequency at Small and Big Diameter Tube

Figure 4.27 shows the comparison between estimated and actual frequency in small diameter tube for air gas. The green line indicates actual frequency inside the tube while the blue line indicates estimated frequency through calculation. It is difficult to find the right peak for air gas during the 1st harmonic even though the estimated frequency for it is 65.95 Hz. Besides that, the highest frequency for estimated frequency is 725.43 Hz while the actual frequency is only 530 Hz. This experiment does not use fire to see the best standing waveform. Therefore, the probability of human error occur is very high since the researcher could not see the standing wave with naked eye.

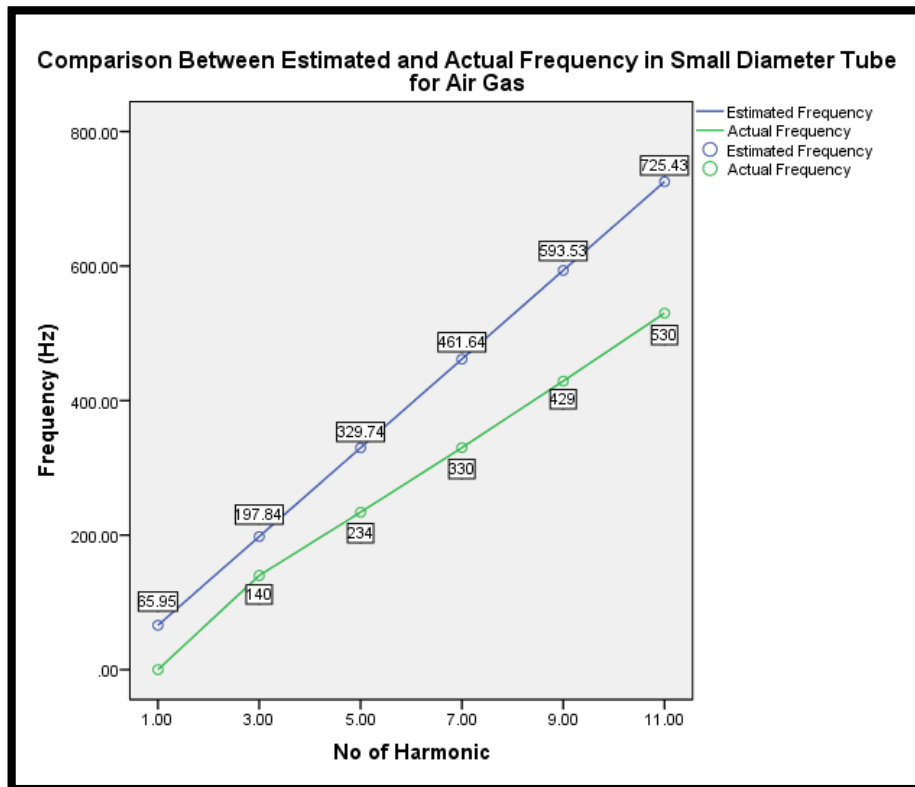


Figure 4.27: Comparison Between Estimated and Actual Frequency in Small Diameter Tube for Air Gas

Figure 4.28 shows the comparison between estimated and actual frequency in big diameter tube for air gas. The green line refers to actual frequency while the blue line refers to estimated frequency inside the tube. Based on the graph, there are different between both frequencies. The 1st harmonic for estimated frequency is 54.46 Hz. However, during the 1st harmonic for actual frequency, the peak could not be detected. This is due to difficulty to find the peak with naked eye while checking the standing wave inside the tube.

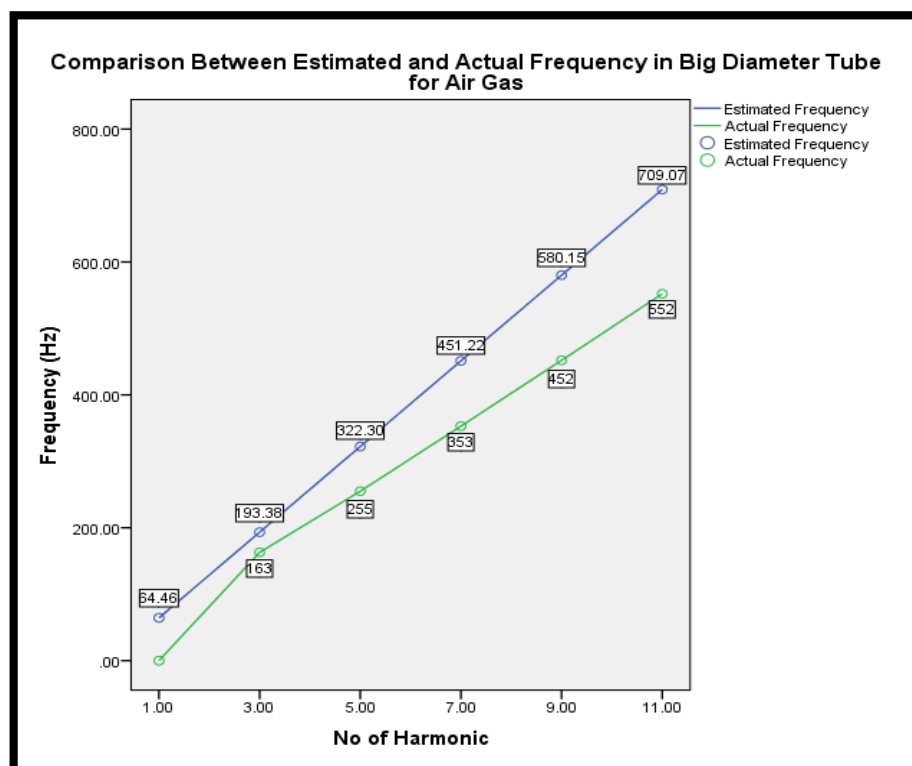


Figure 4.28: Comparison Between Estimated and Actual Frequency in Big Diameter Tube for Air Gas

4. Propane Gas: Estimated Frequency versus Actual Frequency at Small and Big Diameter Tube

Figure 4.29 shows the comparison between estimated and actual frequency in small diameter tube for propane gas. The green line refers to actual frequency inside the tube while the blue line refers to estimated frequency through the calculation. Based on the graph, there were no peak detected through the software Audacity even though the estimated frequency for the 1st harmonic is 47.98 Hz. Apart from that, the difference between the size of diameter tube can be seen through Figure 4.29 which is the actual frequency for the small diameter tube a bit lower than the estimated frequency. However, in Figure 4.30 the big diameter tube has actual frequency higher than the estimated frequency. This is due to big diameter tube has better flame propagation than the smaller tube.

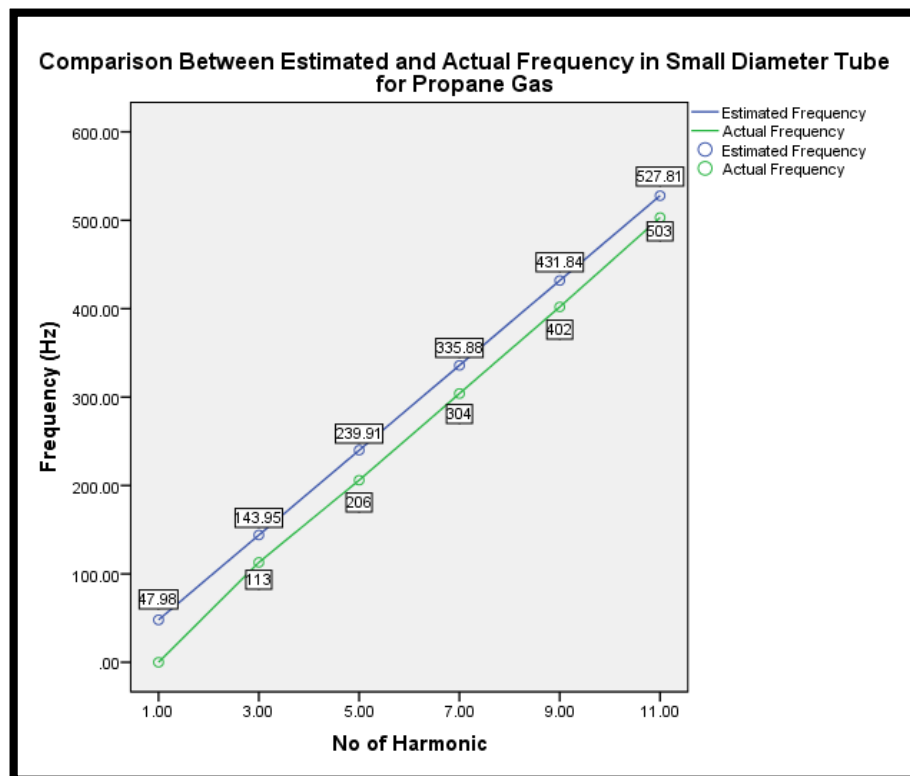


Figure 4.29: Comparison Between Estimated and Actual Frequency in Small Diameter Tube for Propane Gas

Figure 4.30 shows the comparison between the estimated and actual frequency in big diameter tube for propane gas. The green line indicates actual frequency during the experiment while the blue line indicates estimated frequency through the calculation. The actual frequency is a bit higher than the estimated frequency. However, at the 1st harmonic the peak could not be find using the software Audacity due to the flame does not form sinusoidal pattern properly. Therefore, the best standing wave for the 1st harmonic could not be detected. The best standing wave during the 11th harmonic for actual frequency is 549 Hz while for the estimated frequency is 515.90 Hz.

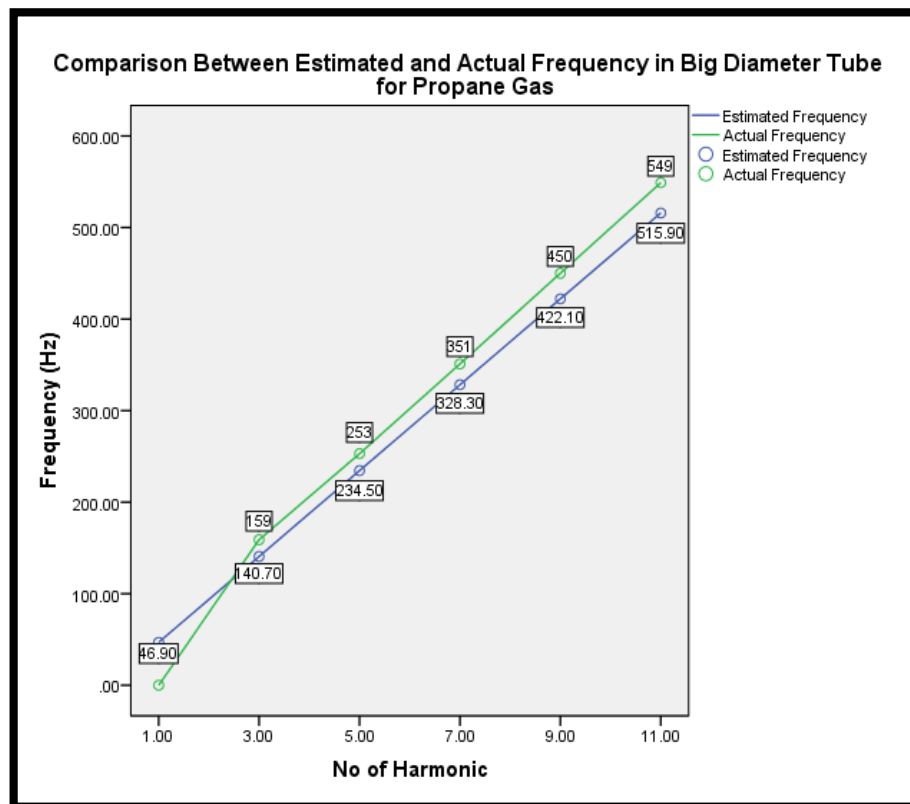


Figure 4.30: Comparison Between Estimated and Actual Frequency in Big Diameter Tube for Propane Gas

5. Small Diameter Tube for Air Gas versus Small Diameter Tube for Propane Gas

Figure 4.31 shows the comparison between the actual frequency recorded in small diameter tube for air gas and small diameter tube for propane gas. The blue line indicates small diameter tube for air gas whereas the green line indicates the small diameter tube for propane gas. Both actual frequency for air gas and propane gas increase when the number of harmonic increases. Nevertheless, the actual frequency for air gas is a bit higher than the propane gas. The highest actual frequency for air gas is 530 Hz while the highest actual frequency for propane gas is 503 Hz. This is due to the difference in molecular weight for both type of gas.

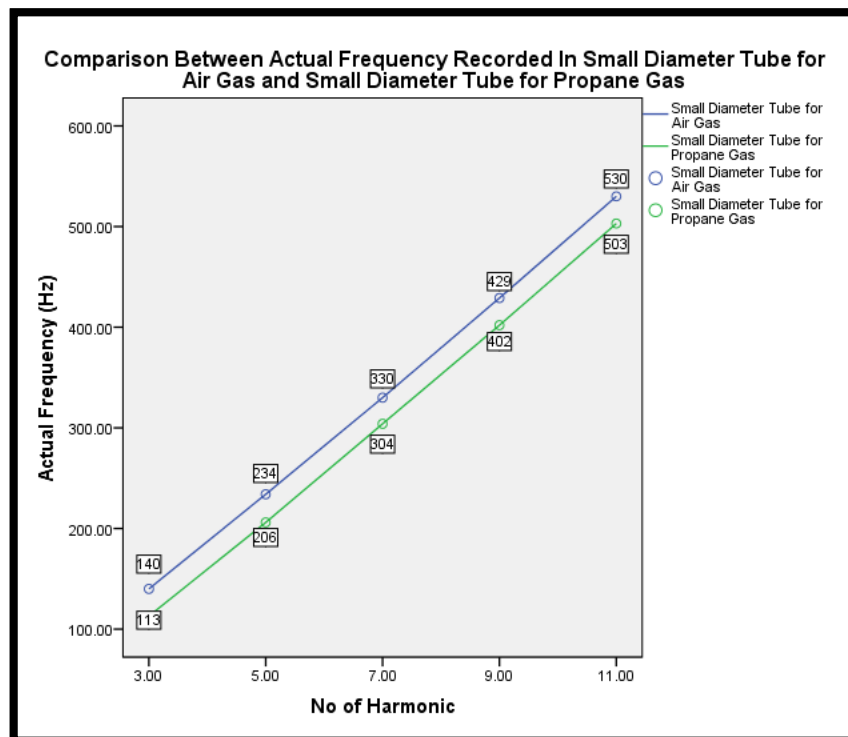


Figure 4.31: Comparison Between Actual Frequency in Small Diameter Tube for Air Gas and Small Diameter Tube for Propane Gas

6. Big Diameter Tube for Air Gas versus Big Diameter Tube for Propane Gas

Figure 4.32 shows the comparison between actual frequency recorded in big diameter tube for air gas and big diameter tube for propane gas. The blue line represents the actual frequency for air gas and the green line represent the actual frequency for propane gas. The actual frequency recorded at each harmonic for both gases only has slightly different from each other. Both gases increase the actual frequency when increase the number of harmonics. However, the actual frequency for air gas a bit higher than propane gas. The highest actual frequency for air gas is 552 Hz while the highest actual frequency for propane gas is 549 Hz. This is due to difference in molecular weight for each gas. Besides, the result for propane more valid and has acceptable data than air gas since, the researcher could see the production of flame above the tube.

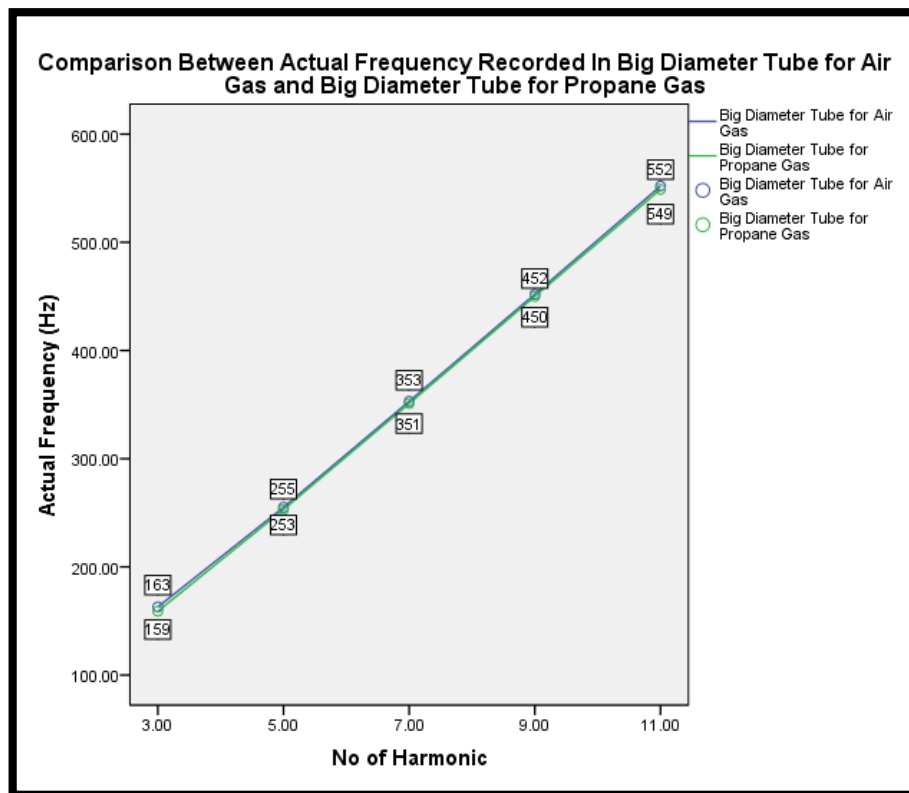


Figure 4.32: Comparison Between Actual Frequency in Big Diameter Tube for Air Gas and Big Diameter Tube for Propane Gas

7. Speed of Gas in Various Medium

Figure 4.33 shows comparison speed of sound in different medium for small diameter tube. The green line refers to speed of sound in propane while the blue line refers to the speed of sound in air. Speed of sound in air through calculation is 342.93 m/s while for propane is 249.51 m/s. As predicted, the speed of sound in air was much higher than in propane. However, the result analysis for both gas show that the result for propane more accurate and acceptable than the air. At the 11th harmonic, the speed of sound in propane is 237.78 m/s while for air is only 250.55 m/s. The value for air is far from the expected value which is 342.93 m/s. This might be due to human error while holding the multimeter to the tube or the way the researcher conducts the experiment without truly expect during the experiment.

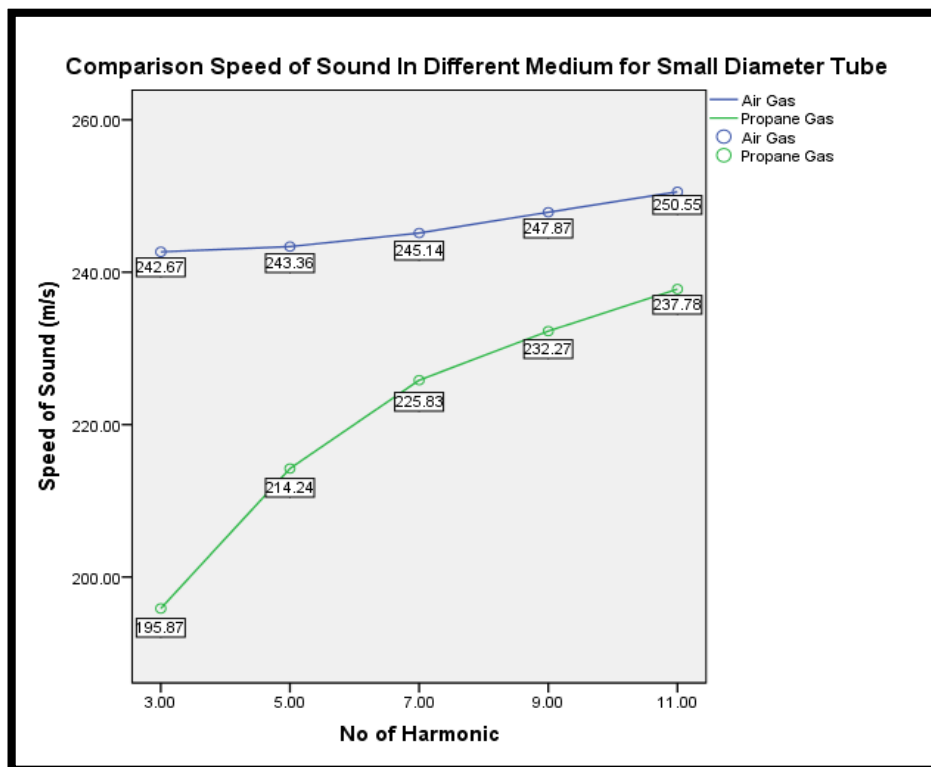


Figure 4.33: Comparison Speed of Sound in Different Medium for Small Diameter Tube

Figure 4.34 shows the comparison speed of sound in different medium for big diameter tube. The green line refers to speed of sound in propane while the blue line refers to speed of sound in gas. Based on the calculation, the speed of sound in air is 342.93 m/s while for propane is 249.51 m/s. As predicted, the speed of sound in air was much higher than in propane. However, the speed of sound in propane is more accurate than the air. At the 11th harmonic, the speed of sound in propane is 265.52 m/s whereas in air is 266.97 m/s. The percentage error for propane is 6.03% whereas for air is 28.45%. It shows that the propane has better result than the air due to production of flame above the tube for propane gas make it easier to calculate the data.

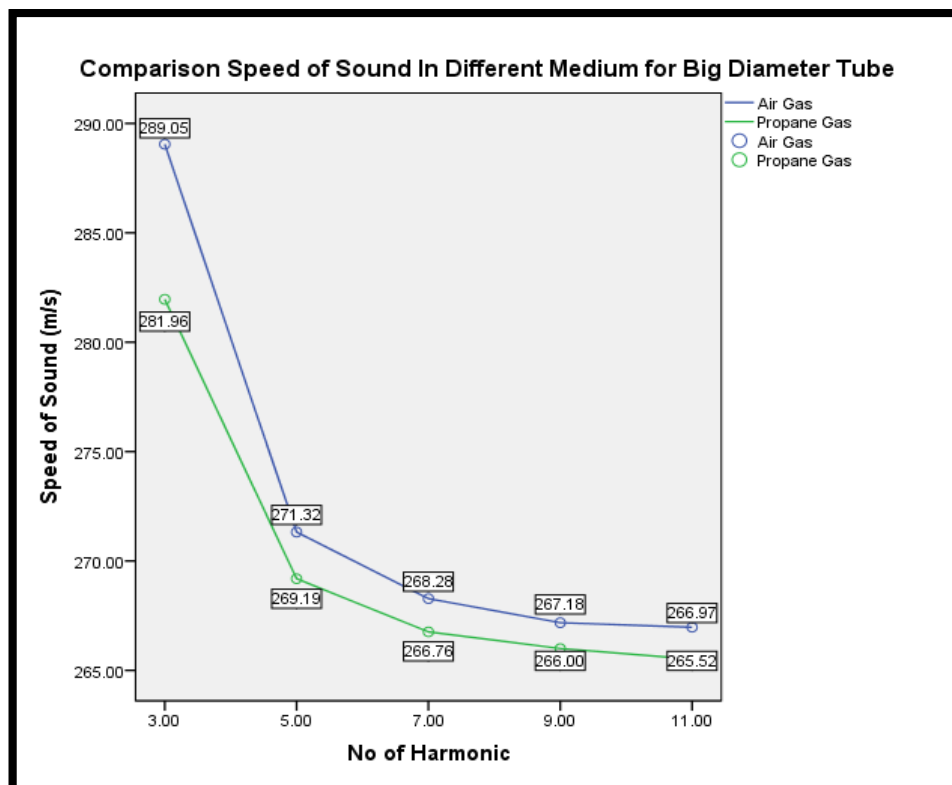


Figure 4.34: Comparison Speed of Sound in Different Medium for Big Diameter Tube

4.7 Summary

Statistical result of all analysis has been successfully presented in this chapter. The analysis of data shows values for frequency analysis for 1st to 11th harmonic, speed of sound in various mediums and the flame propagation for different tube diameters. For other analysis of data are shown through Appendices. From the findings, Ruben's Tube can be made into an instrumentation system by using the numerical software which is the frequency generator would be no longer needed and experiment would be fully controlled by the software. Also, air has higher speed of sound in both tube diameter than the propane. However, the propane has more valid and acceptable data than the air since, the value speed of sound for theory and experiment for propane near to each other. The larger tube diameter also makes the flame accelerates faster, hence, when the flame touches the tube walls it would generate stronger pressure waves. This would lead to higher pressure oscillations that generate more flame structure.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This chapter consists of summary for results of data analysis in this research study. The summaries for using numerical software as a frequency generator has been discussed in this chapter. In addition to that, recommendation to improve on making Ruben's tube into instrumentation system by using numerical software were discussed in this chapter.

Based on this experiment, the first objective which is to show the pattern of standing wave using numerical software that is Audacity is achieved. The experiment no longer used frequency generator and only used the software to change frequency for each experiment. The speed of sound also can be found using this software. Hence, the Ruben's tube can be used well as a laboratory and class demonstration kit. It has better approach and the operation is simple. Since, some basic concepts and theories of the course can be represented by figures or course produced by the flame, the basic principles can be understood much easier. The integrated system of Ruben's tube not only enhances the efficiency of teaching, but also it can help to further improve the quality of teaching.

However, calculating sound speed, frequencies and temperature during the experiment using numerical software might be not a straightforward exercise of basic acoustics. This is due to human error and environment in the laboratory while conducting the experiment. For example, this experiment supposedly to be conducted in a closed room, but there is air conditioner at the upward position of the Ruben's tube while doing the experiment.

Besides, the second achieved objective is to discover the relationship between speed of sound in different gas air and propane. As expected, the speed of sound in air was much higher than in propane. However, the result of speed in propane was more accurate than in air. The propane gas has more valid and acceptable data than the air since, the value of speed of sound for theory and experiment for propane near to each other. Also, this could be due to both air and propane has different molecular weight and the test for both gases were done on different day in different environment.

Apart from that, the third objective, also achieved, which is to discover the effect of larger and smaller diameter tube with flame propagation velocity can be found in this experiment. It is found that flame propagation velocity increases with tube diameter. Based on the graph analysis, the bigger tube diameter would make flame accelerates faster. Hence, when the flame touches the tube side walls, the stronger pressure wave would be generated and more flame structure are formed.

Also, small diameter tube of Ruben's tube will decrease the resonance shift and the appearance of fire is not noticeable even though the frequencies keep getting higher. Using small diameter tube also could compromise the effectiveness of the demonstration than using the bigger diameter tube. Therefore, bigger diameter tube has better changes in flame shape than small diameter tube. It increases in burning surface area and has better stability of the integrated system. This has proven that difference sizes of tube diameter have effects in the design of piping system to optimize heat transfer in the system.

5.2 Recommendations for Future Work

This experiment has a potential to be done in three-dimension Ruben's tube. The presentation of standing wave will be interesting to watch. However, the cost will be higher and the explanation of standing wave behavior will be different than the two-dimension Ruben's tube. Also, the process to build three-dimension scale will have difficulties since the mechanisms will be more complicated and need experts in this area to proceed.

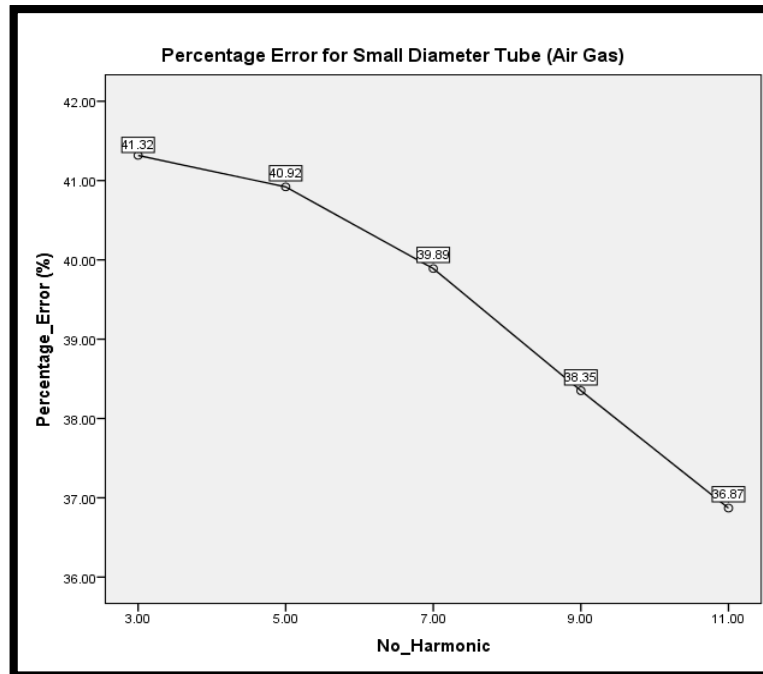
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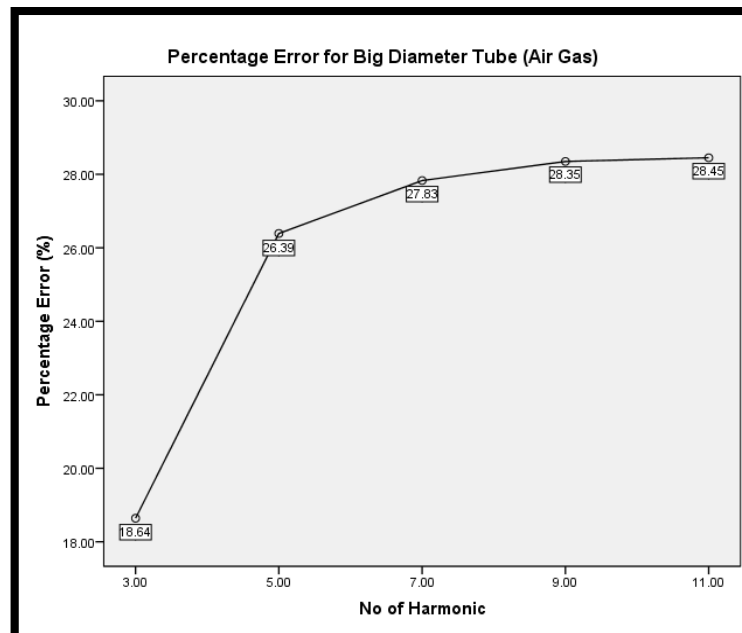
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APPENDICES

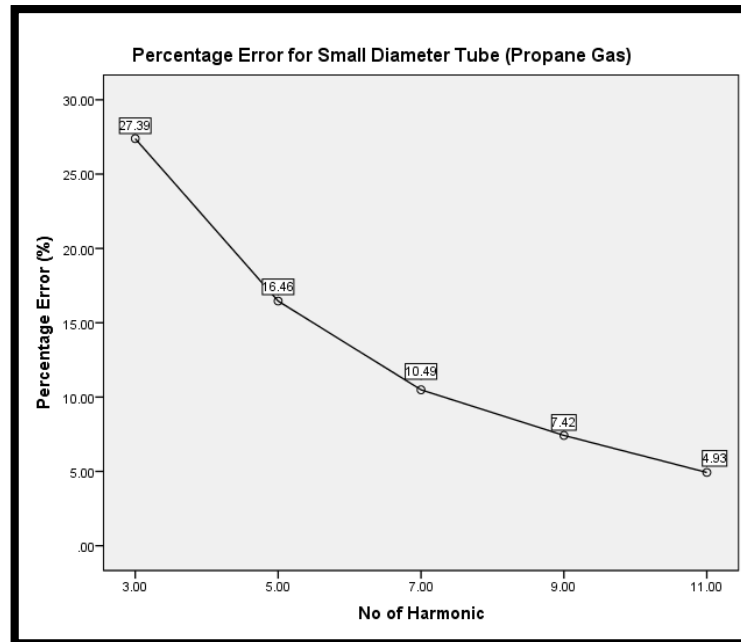
1. Air Gas: Percentage Error for Small Tube Diameter



2. Air Gas: Percentage Error for Big Tube Diameter



3. Propane Gas: Percentage Error for Small Tube Diameter



4. Propane Gas: Percentage Error for Big Tube Diameter

